Magnetically disordered systems studied using neutron polarization analysis

Or-

Getting rid of non-magnetic scattering

"completely uninteresting"

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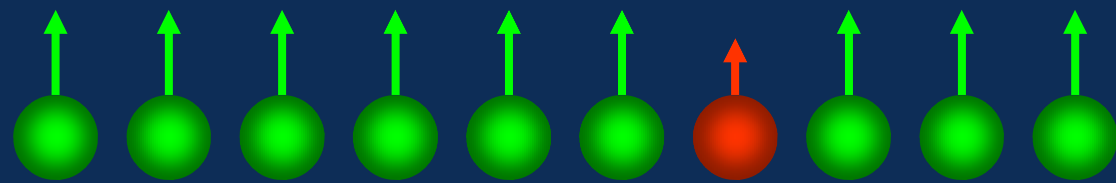
Outline

- Historical Intro – magnetic defect scattering
- NPA instrumentation
- Magnetic separation using PA
- Examples: CrFe
  CuMn
  Quasicrystals
  MnO
- RMC and polarization analysis
- PA on pulsed sources:
  D7/SPAN
  Supermirrors & ^{3}He
  PA and 2d detectors

Simple dilute defects in ferromagnetic 3d transition metal hosts



Laue monotonic (LM) scattering: $$\left(\frac{d\sigma}{d\Omega}\right)_N = c(1-c)(b_A - b_B)^2$$

Magnetic scattering length: $$p = \frac{g\,e^2}{2m_e}\langle m_J \rangle\, f(\boldsymbol{\kappa})[\mathbf{P}.\mathbf{q}]$$

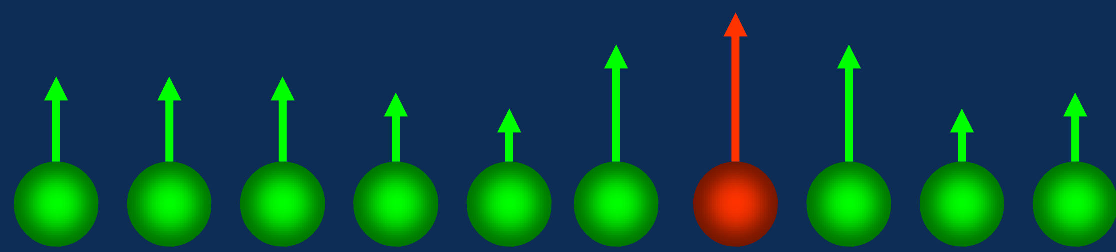
Sign depends on neutron polarization ($\mathbf{P}$ = +/- 1)

$\mathbf{q}$ is the magnetic interaction vector, ie $\mathbf{q} = \hat{\boldsymbol{\kappa}}(\hat{\boldsymbol{\kappa}}.\hat{\boldsymbol{\eta}}) - \hat{\boldsymbol{\eta}}$

Magnetic LM scattering: $$\left(\frac{ds}{d\Omega}\right)_M = c(1-c)q^2\left(\frac{g\,e^2}{2m_e}\right)^2[m_A f_A(\boldsymbol{\kappa}) - m_B f_B(\boldsymbol{\kappa})]^2$$

$$q^2 = 1 - (\hat{\boldsymbol{\kappa}}.\hat{\boldsymbol{\eta}})^2 = \frac{2}{3}$$ for a randomly oriented magnet

Extended dilute defects in ferromagnetic 3d transition metal hosts



Laue monotonic (LM) scattering: $$\left(\frac{d\sigma}{d\Omega}\right)_N = c(1-c)(b_A - b_B)^2$$

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Magnetic LM scattering: $$\left(\frac{ds}{d\Omega}\right)_M = c(1-c)q^2\left(\frac{g\,e^2}{2m_e}\right)^2[m_A f_A(\boldsymbol{\kappa}) - m_B f_B(\boldsymbol{\kappa}) + \Phi(\boldsymbol{\kappa})]^2$$

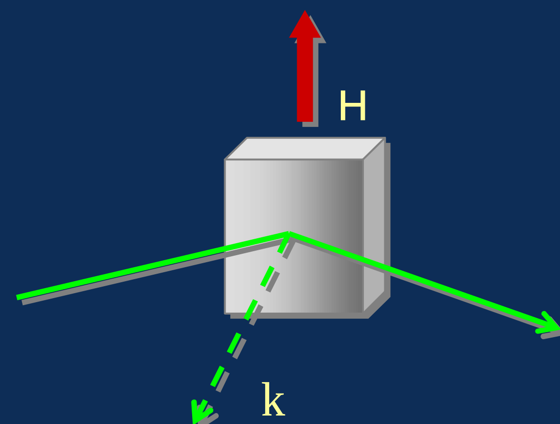
$$q^2 = 1 - (\hat{\boldsymbol{\kappa}}.\hat{\boldsymbol{\eta}})^2 = \frac{2}{3}$$ for a randomly oriented magnet

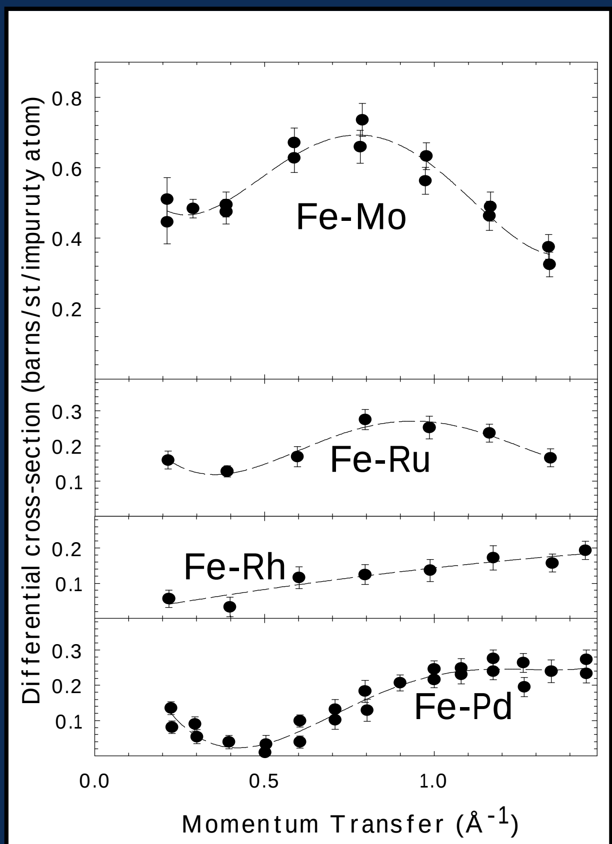
Diffuse magnetic scattering of unpolarized neutrons

$$\left(\frac{ds}{d\Omega}\right) = \left(\frac{ds}{d\Omega}\right)_N + \left(\frac{ds}{d\Omega}\right)_M$$

For H $\perp$ k : $q^2 = 1$

For H || k : $q^2 = 0$ (i.e. no magnetic scattering)





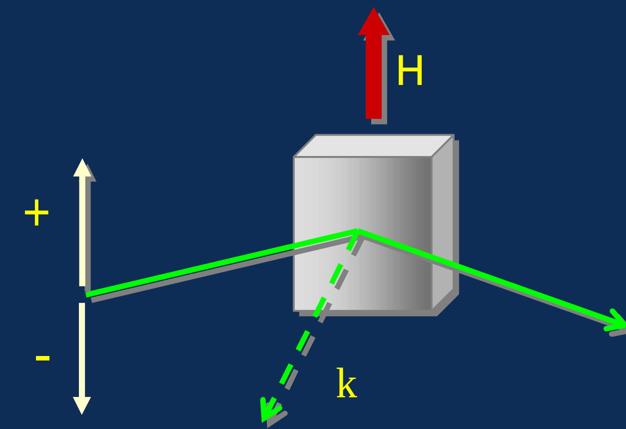
$$\left(\frac{ds}{d\Omega}\right)_{\mathbf{H}\perp\boldsymbol{\kappa}} - \left(\frac{ds}{d\Omega}\right)_{\mathbf{H}\parallel\boldsymbol{\kappa}} \propto [m_A f_A(\boldsymbol{\kappa}) - m_B f_B(\boldsymbol{\kappa}) + \Phi(\boldsymbol{\kappa})]^2$$

Note: possible ambiguities in relative direction of magnetic defect and host magnetisation

Collins and Low, Proc Phys Soc 86 (1965) 535

Diffuse magnetic scattering from defects in ferromagnets: Polarized neutron methods

Additional PA dependent term



$$\left(\frac{ds}{d\Omega}\right)_{\pm} = \left(\frac{ds}{d\Omega}\right)_{N} \pm \left(\frac{ds}{d\Omega}\right)_{NM} + \left(\frac{ds}{d\Omega}\right)_{M}$$

$$\left(\frac{ds}{d\Omega}\right)_{NM} = c(1-c)\left(\frac{g e^2}{2m_e}\right)\underline{(b_A - b_B)}[m_A f_A(\boldsymbol{\kappa}) - m_B f_B(\boldsymbol{\kappa}) + \Phi(\boldsymbol{\kappa})]$$

The difference between spin-up and spin down scattering gives

$$\Delta\left(\frac{ds}{d\Omega}\right) = \left(\frac{ds}{d\Omega}\right)_{+} - \left(\frac{ds}{d\Omega}\right)_{-} = 2\left(\frac{ds}{d\Omega}\right)_{NM}$$

NB: Good signal relies on good nuclear scattering contrast

Note that:

$$\Delta\left(\frac{ds}{d\Omega}\right)_{k=0} = 2\left(\frac{g e^2}{2m_e}\right)c(1-c)(b_A - b_B)\frac{d\bar{m}}{dc}$$

where $\frac{d\bar{\mu}}{dc}$ can be obtained from bulk magnetisation measurements

Magnetic defects in ferromagnetic FeMn alloys

D7 (1976): Polarized beam diffraction
Fe -2.8at%Mn (dilute defect limit)

Assumed in the analysis that $f_{Fe}(\kappa) = f_{Mn}(\kappa)$

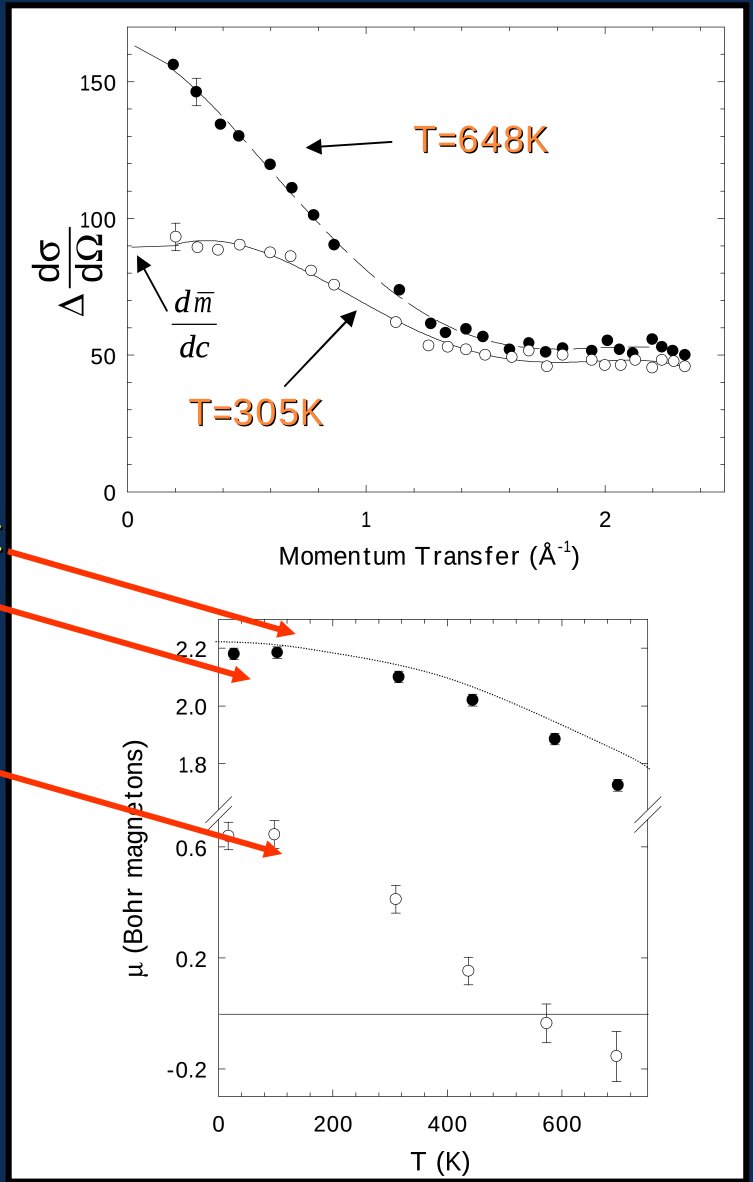
$\Phi(\kappa)$ is the spherically averaged Fourier transform of the single atom moment disturbance $\Delta\mu$ on the host Fe atoms at a distance r from the impurity Mn atoms.

i.e. $\mu_{Fe} = \mu_{Fe\ pure} - \Delta\mu$

Pure Fe moment

Fe moment

Mn moment



Mezei, Proc Conf. Neutron Scatt., Gatlinberg 1976

PA diffuse scattering Instrumentation

D7 (ILL, c. 1972)

Polarization analysis installed between 1980 and 1990

Polarized flux:
~ 1.6×10^6

Analyser coverage:
0.11 sr
(in 2004: 0.19 sr
in 2006: 0.375 sr)

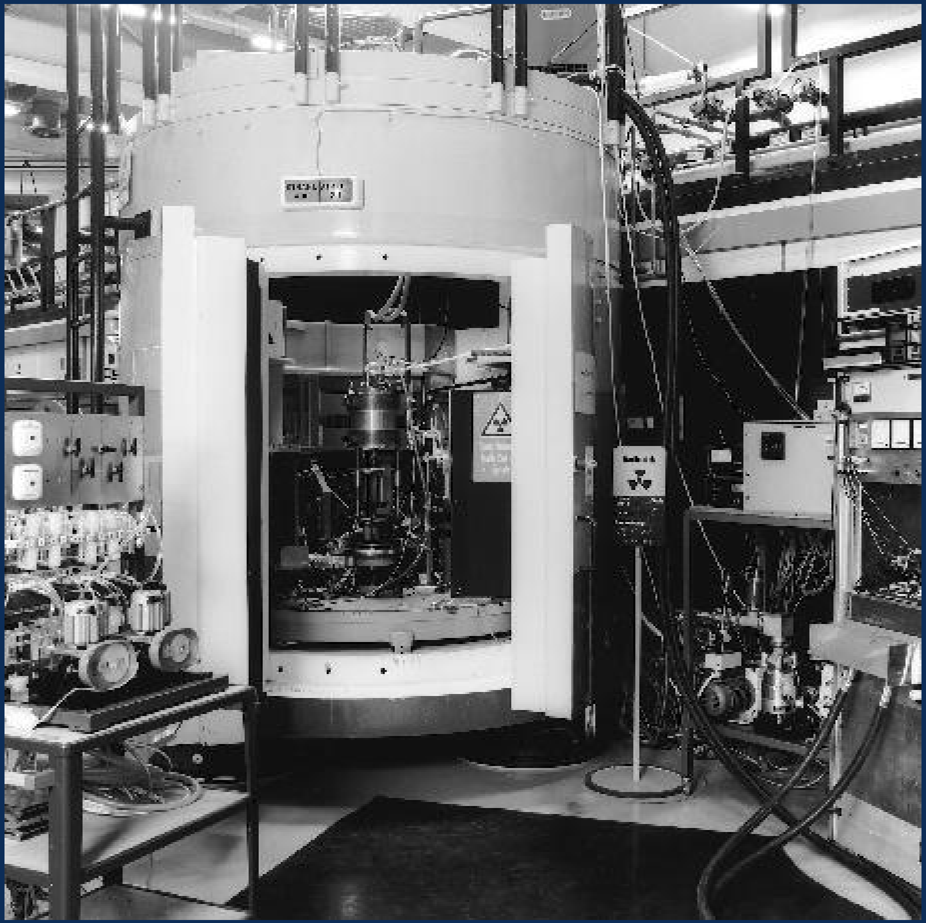
PA diffuse scattering Instrumentation

DNS (FRJ-II, FZJ)

See next talk…..

Polarized flux: high!

Solid angle coverage: less!

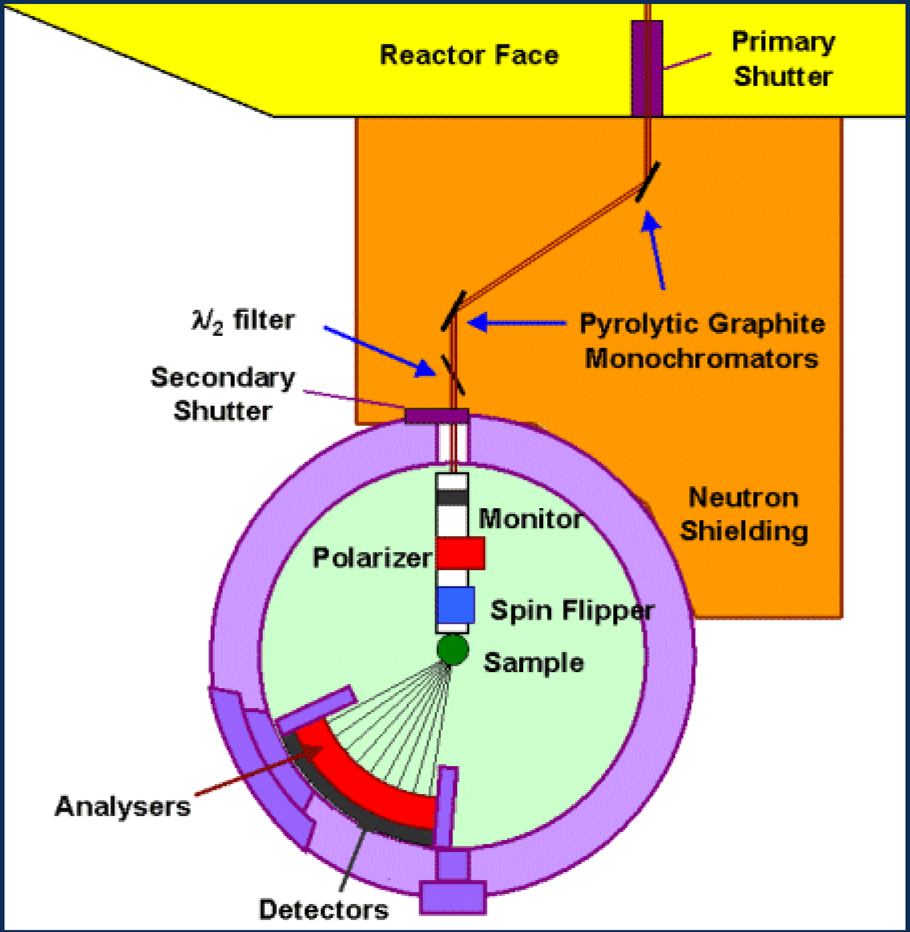


PA diffuse scattering Instrumentation

LONGPOL (HIFAR, Ansto)

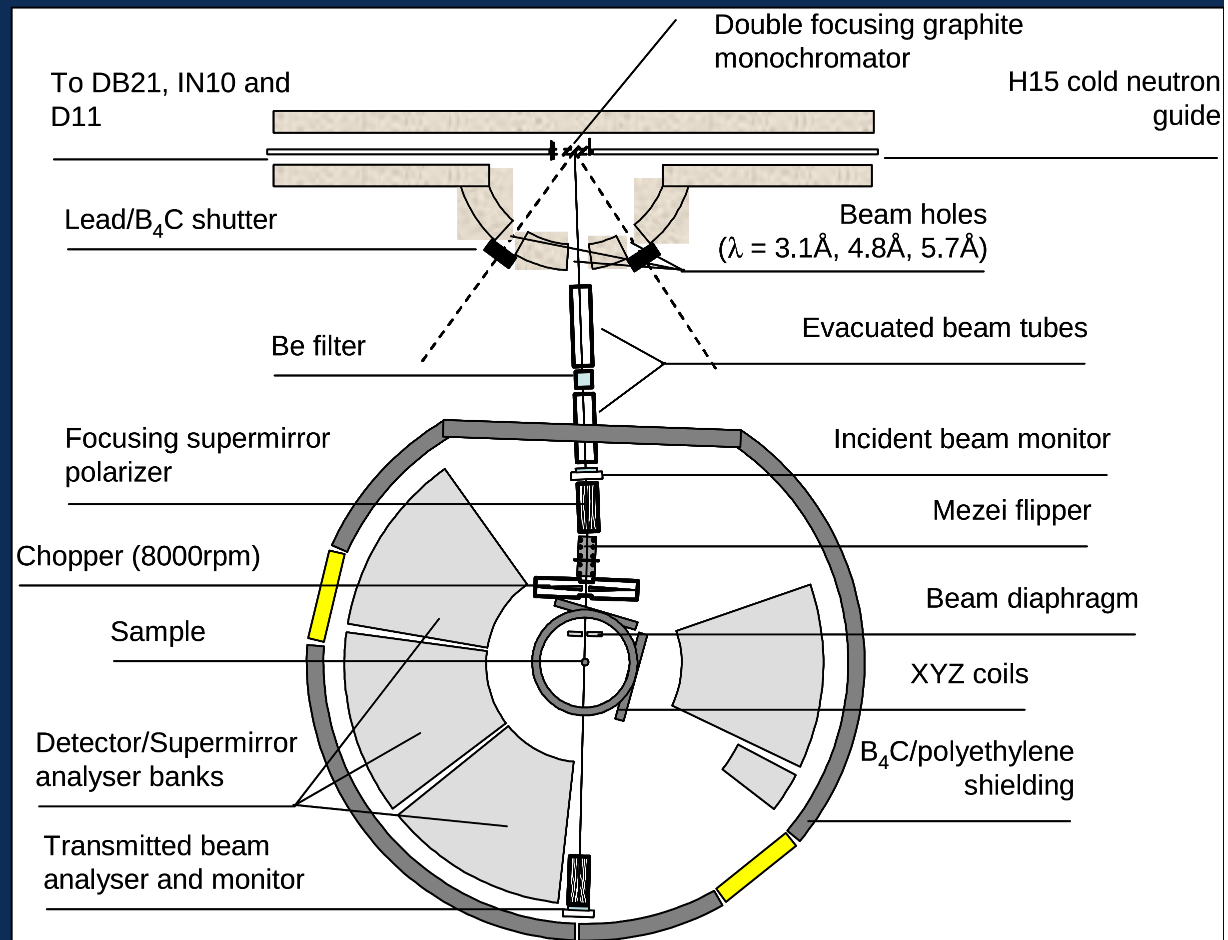
Polarized flux: 2×10^4

Solid angle coverage: ~ 0.02 sr



D7

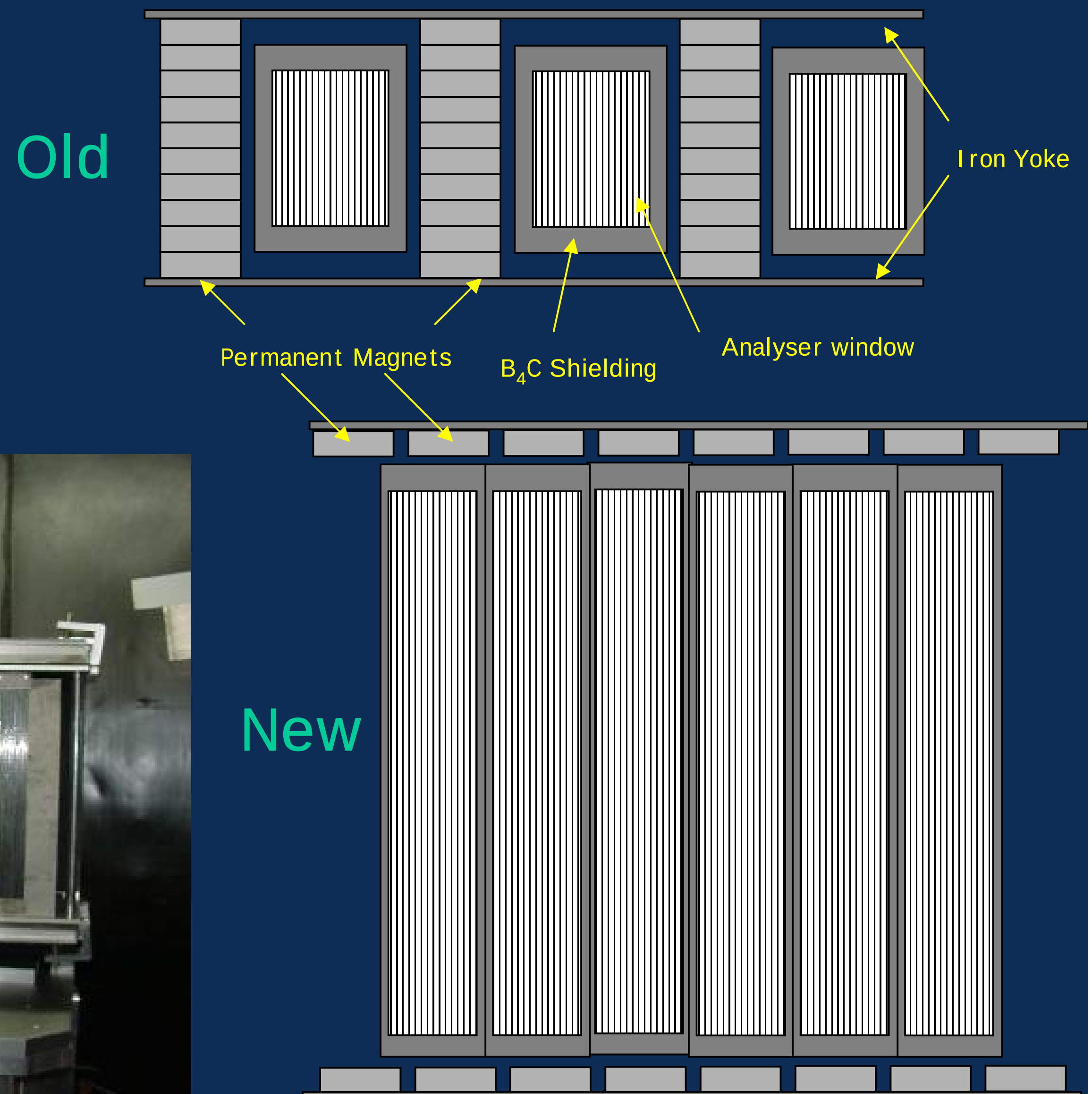
- Diffuse scattering
- Cold neutrons
- 6000 supermirrors
- 42 detectors
- 1-directional polarization analysis: Separation of coherent and incoherent scattering
- 3-directional polarization analysis: Separation also of magnetic scattering
- Time-of-flight

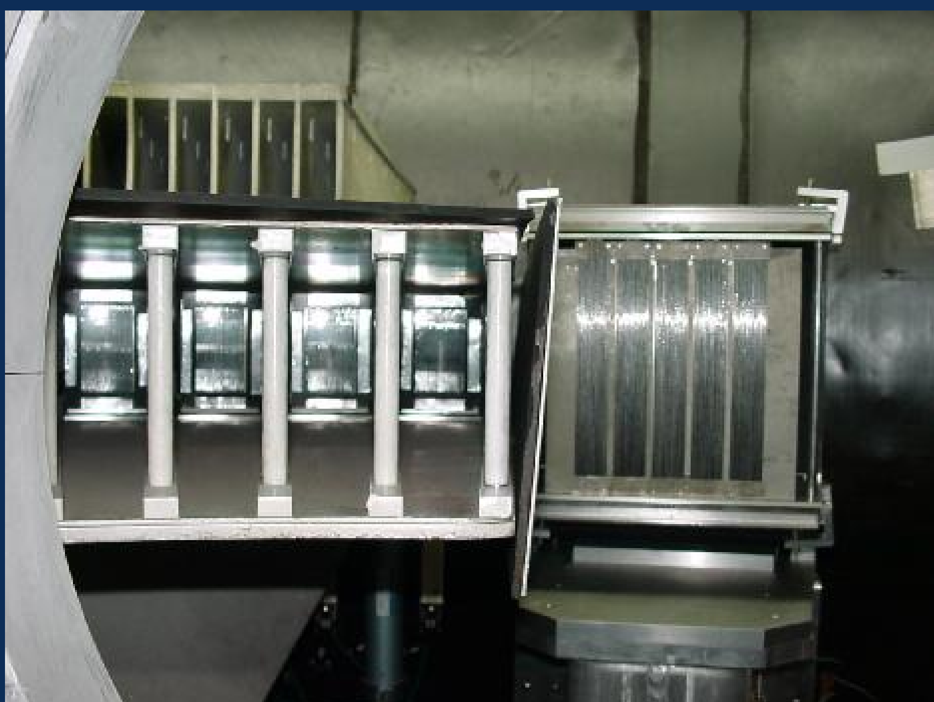


D7 Analyser upgrade (supermirrors)

Solid angle gain:
× 6.1
Flux gain:
× 3
Transmission gain:
× 3

Total gain:
× 50





The price of PA

- Only PA can unambiguously separate magnetic from nuclear scattering, but at a high cost in counting time:
  - Transmission of supermirror benders ~ 0.25-0.30
  - 3-directional PA requires 6 measurements
  - Magnetic scattering is the difference between 3 measurements
- Equivalent counting time ~ 150 times unpolarized experiment
- Limit of presently feasible D7 experiments:
  - Magnetic moments > ~ 0.5 μ_B/f.u.
  - Single crystals > ~ 2 cm^3
  - Quasistatic approximation: $|h\omega|$ < ~ 3 meV
  - T. O. F. : E_{res} = 0.5meV
- Breakdown of experiments on D7: 3% unpolarized chopper
0% unpolarized integral
15% polarized chopper
82% polarized integral

General 3-directional polarization analysis

Q is always in x-y plane –

$$\frac{\boldsymbol{\kappa}}{k} = \begin{pmatrix} \cos a \\ \sin a \\ 0 \end{pmatrix}$$

- These are the diagonal terms of the full 3d polarization tensor.

$$\begin{bmatrix} S_{xx} & S_{xy} & S_{xz} \\ S_{yx} & S_{yy} & S_{yz} \\ S_{zx} & S_{zy} & S_{zz} \end{bmatrix}$$

$$\left(\frac{d\sigma}{d\Omega}\right)_X^{SF} = \frac{1}{2}(\cos^2\alpha + 1)\left(\frac{d\sigma}{d\Omega}\right)_{MAG} + \frac{2}{3}\left(\frac{d\sigma}{d\Omega}\right)_{SI}$$

$$\left(\frac{d\sigma}{d\Omega}\right)_X^{NSF} = \frac{1}{2}(\sin^2\alpha + 1)\left(\frac{d\sigma}{d\Omega}\right)_{MAG} + \frac{1}{3}\left(\frac{d\sigma}{d\Omega}\right)_{SI} + \left(\frac{d\sigma}{d\Omega}\right)_{NC} + \left(\frac{d\sigma}{d\Omega}\right)_{II}$$

$$\left(\frac{d\sigma}{d\Omega}\right)_Y^{SF} = \frac{1}{2}(\sin^2\alpha + 1)\left(\frac{d\sigma}{d\Omega}\right)_{MAG} + \frac{2}{3}\left(\frac{d\sigma}{d\Omega}\right)_{SI}$$

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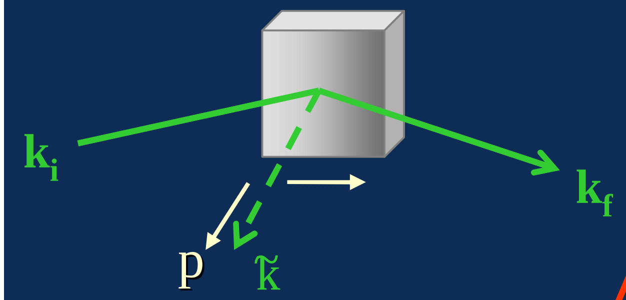
Blume, PR 130 (1963) 1670, Moon, Riste and Koehler PR 181 (1969) 920,
Scharpf and Capellmann Phys Stat Sol a135 (1993) 359

Neutron Polarization Analysis:
The parallel-perpendicular method (P - ⊥)

Simple polarisation analysis geometry
eg early LONGPOL
D5 (ILL)



$\alpha = 0, \pi/2$

$$\hat{P}\cdot\hat{k} = 1 : a = 0$$

$$\left(\frac{ds}{d\Omega}\right)_{SF} = \left(\frac{ds}{d\Omega}\right)_{MAG} + \frac{2}{3}\left(\frac{ds}{d\Omega}\right)_{SI}$$

$$\hat{P}\cdot\hat{k} = 0 : a = p/2$$

$$\left(\frac{ds}{d\Omega}\right)_{SF} = \frac{1}{2}\left(\frac{ds}{d\Omega}\right)_{MAG} + \frac{2}{3}\left(\frac{ds}{d\Omega}\right)_{SI}$$

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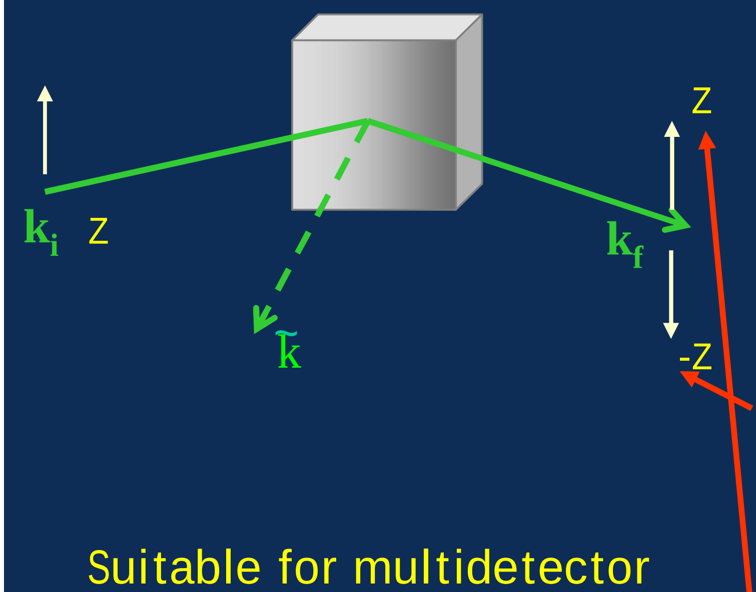
NB. Only works for a single detector, and a single energy transfer

Ziebeck and Brown J. Phys. F 10 2015

Neutron Polarization Analysis: The Z-up/down method (non-magnetic systems)

"Z-up / Z-down" mode



$$\left(\frac{d\sigma}{d\Omega}\right)_X^{SF} = \frac{1}{2}(\cos^2\alpha + 1)\left(\frac{d\sigma}{d\Omega}\right)_{MAG} + \frac{2}{3}\left(\frac{d\sigma}{d\Omega}\right)_{SI}$$

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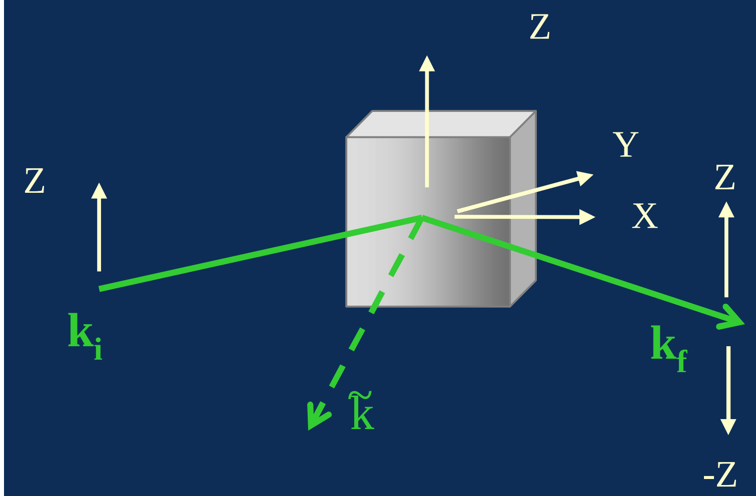
$$\left(\frac{d\sigma}{d\Omega}\right)_Z^{NSF} = \frac{1}{2}\left(\frac{d\sigma}{d\Omega}\right)_{MAG} + \frac{1}{3}\left(\frac{d\sigma}{d\Omega}\right)_{SI} + \left(\frac{d\sigma}{d\Omega}\right)_{NC} + \left(\frac{d\sigma}{d\Omega}\right)_{II}$$

Suitable for multidetector experiments where either $\sigma_{MAG} = 0$ or $s_{SI} = 0$

Gabrys, Physica B 267-268 (1999) 122

Neutron Polarization Analysis: 3-directional polarization analysis

"XYZ" mode



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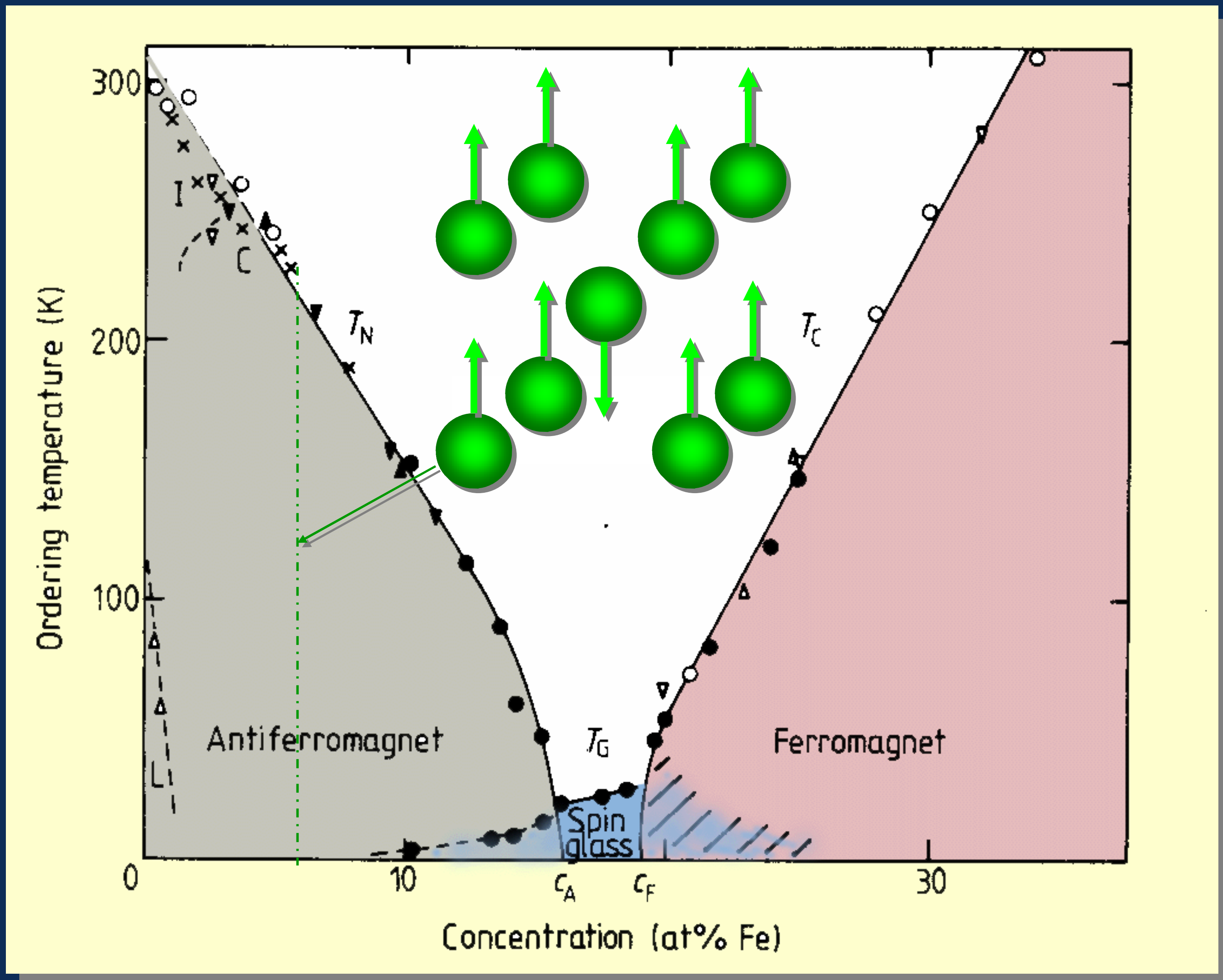
$$\left(\frac{d\sigma}{d\Omega}\right)_{MAG} = 2\left[\left(\frac{d\sigma}{d\Omega}\right)_{SF}^{X} + \left(\frac{d\sigma}{d\Omega}\right)_{SF}^{Y} - 2\left(\frac{d\sigma}{d\Omega}\right)_{SF}^{Z}\right]$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{MAG} = 2\left[2\left(\frac{d\sigma}{d\Omega}\right)_{NSF}^{Z} - \left(\frac{d\sigma}{d\Omega}\right)_{NSF}^{X} - \left(\frac{d\sigma}{d\Omega}\right)_{NSF}^{y}\right]$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{SI} = \frac{1}{2}\left(\frac{d\sigma}{d\Omega}\right)_{TSF} - \left(\frac{d\sigma}{d\Omega}\right)_{MAG}$$

$$\left(\frac{d\sigma}{d\Omega}\right)_{NUC} + \left(\frac{d\sigma}{d\Omega}\right)_{II} = \frac{1}{6}\left[2\left(\frac{d\sigma}{d\Omega}\right)_{TNSF} - \left(\frac{d\sigma}{d\Omega}\right)_{TSF}\right]$$

$Cr_{1-c}Fe_c$: magnetic impurities in a SDW (P - ⊥)



Cywinski and Hicks, J Phys F 10 (1980) 693

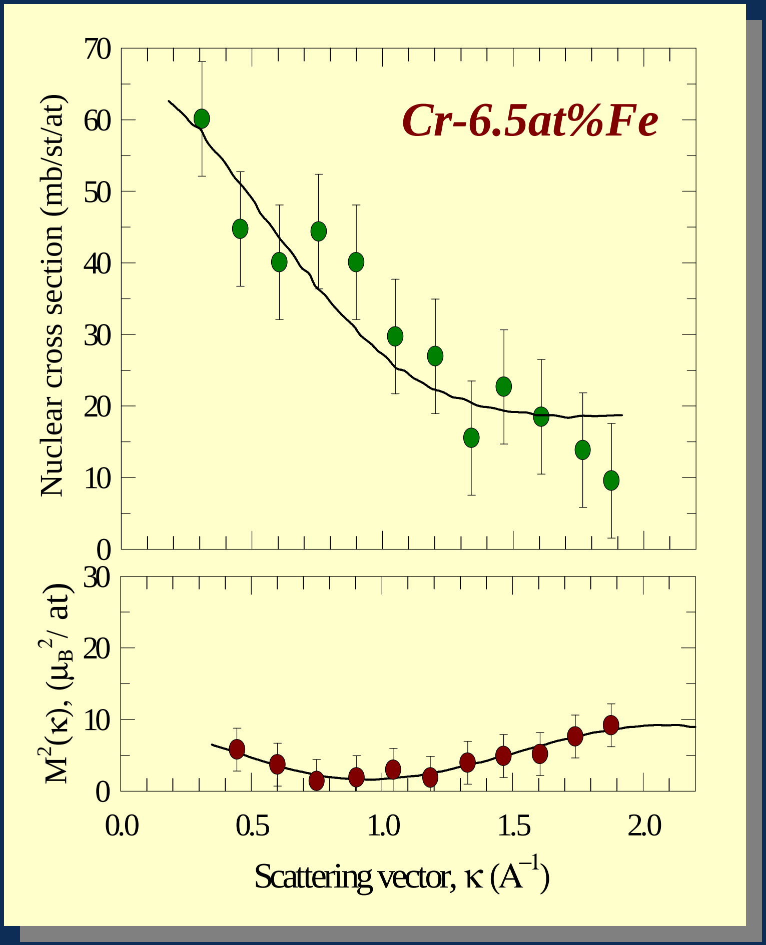
$Cr_{1-c}Fe_c$: magnetic impurities in a SDW

- Fe atoms cluster:

  each Fe atom has 1.6 Fe atoms in its near neighbour shell
- $\mu_{Fe} - \mu_{Cr} = -0.60 \pm 0.08\ \mu_B$

  But $\overline{\mu}=0.68\ \mu_B$, therefore within error there is no moment on the Fe atom
- $g_{Cr}(R_1) = 0.58\ \mu_B : g_{Cr}(R_2) = -0.55\ \mu_B$

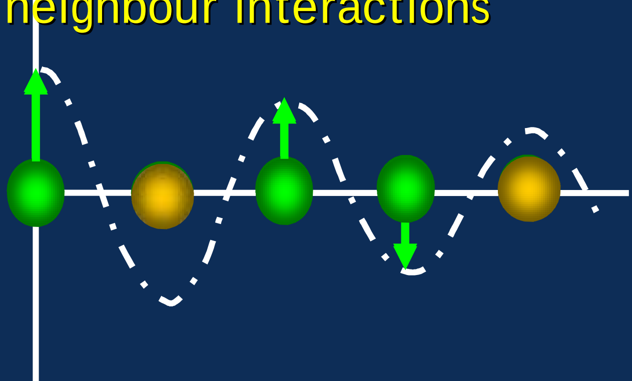
  The amplitude of the surrounding SDW is reduced almost to zero in the first two near neighbour shells around an Fe impurity

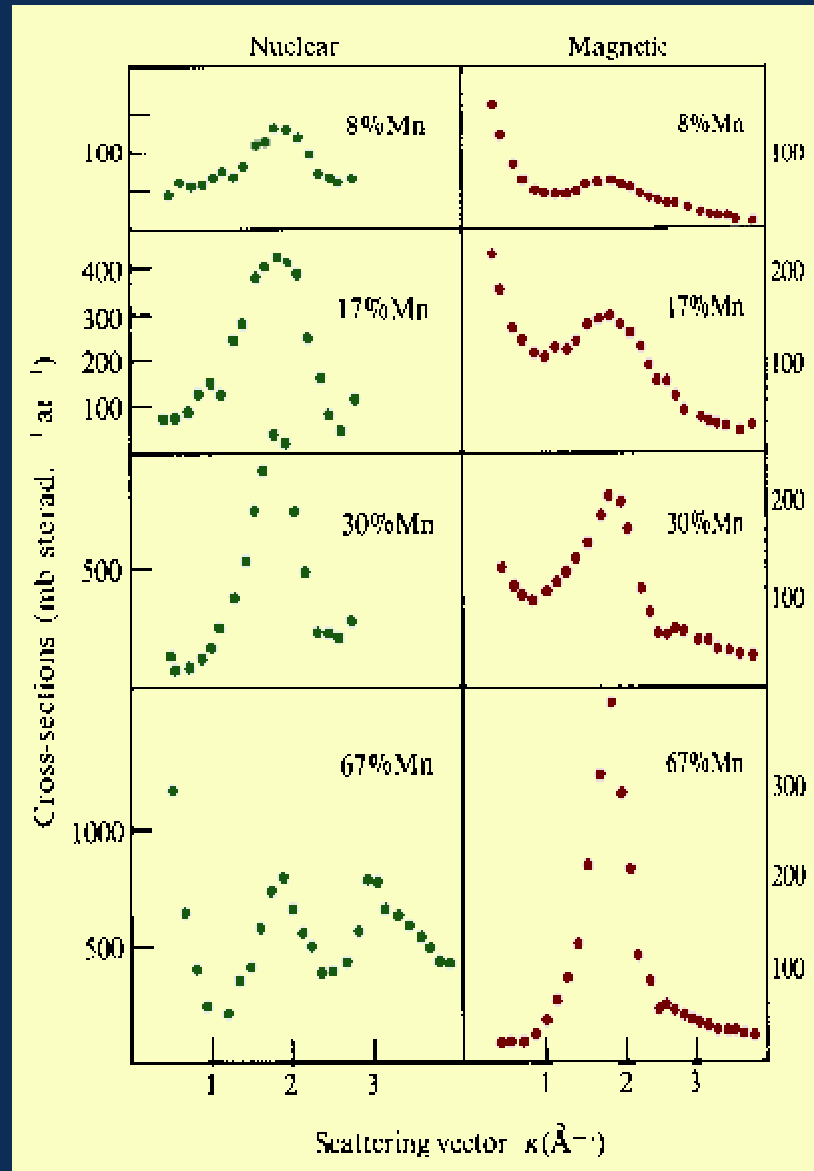


Cywinski and Hicks, J Phys F 10 (1980) 693

Polarization analysis studies of $Cu_{1-c}Mn_c$

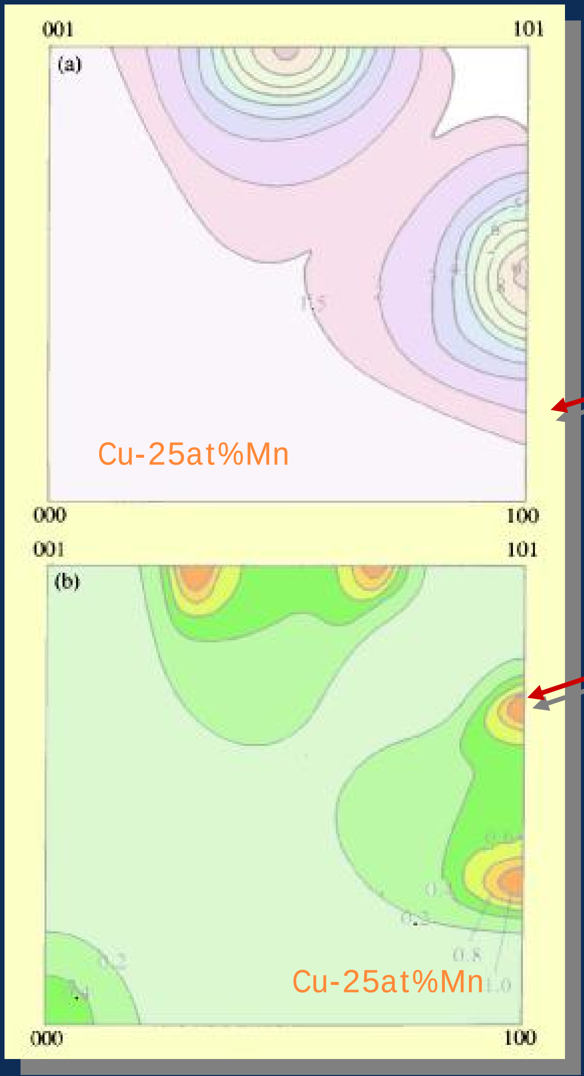
- Mn atoms have a tendency to anticluster
- An oscillatory RKKY-like interaction leads to
    - antiferromagnetic near neighbour
    - ferromagnetic next near neighbour interactions

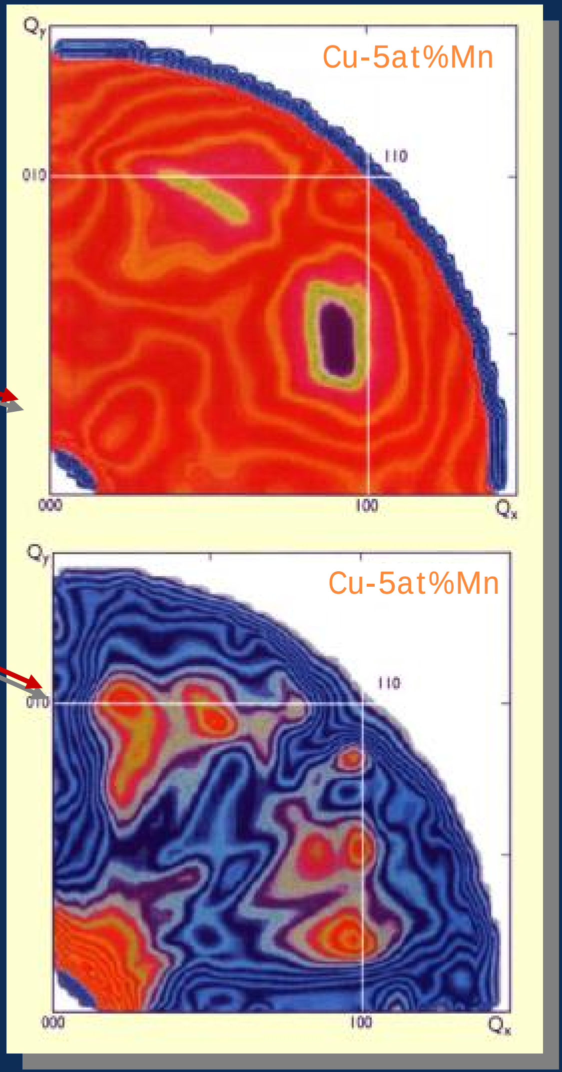




Davis, Burke and Rainford JMMM 15-18 (1980) 151

Polarization analysis studies of $Cu_{1-c}Mn_c$





Nuclear scattering

Magnetic scattering

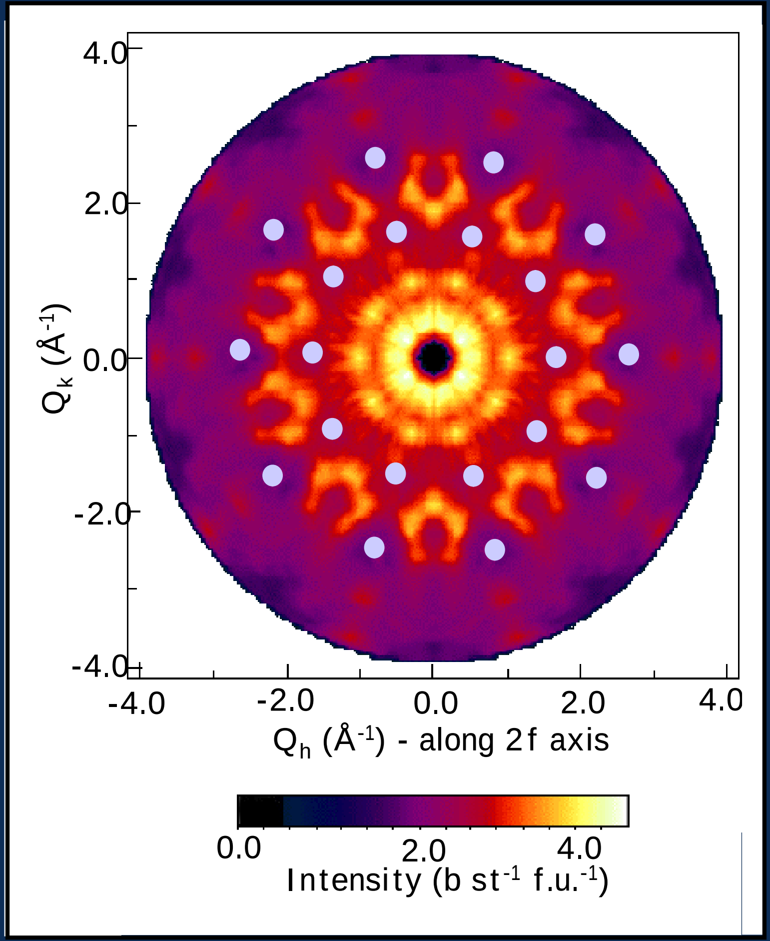
Evidence for SDW-like features around the (1, ½+δ,0) positions

Cable, Werner and Felcher, PRB29 (1984) 1268

Murani et al, Physica B 267-268 (1999) 131

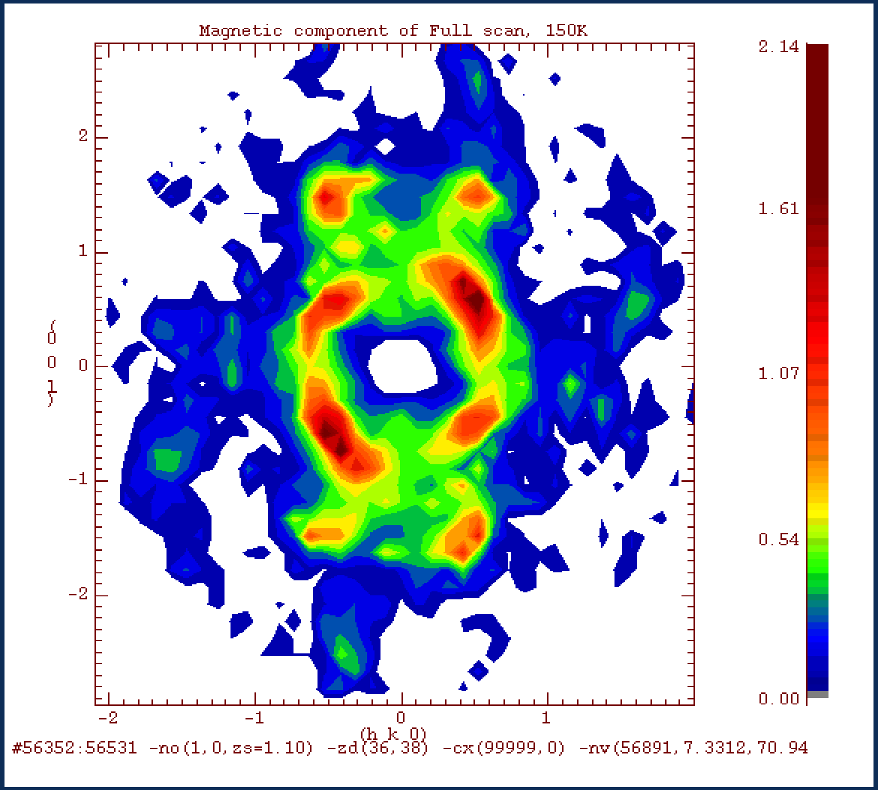
Polarization analysis studies of quasi-crystalline Zn-Mg-Ho

- Despite apparent spin-glass order, strong diffuse peaks with small "background".
- Blue circles represent positions of nuclear peaks
- Apparent that strong antiferromagnetic correlations exist – despite unremarkable bulk susceptibility

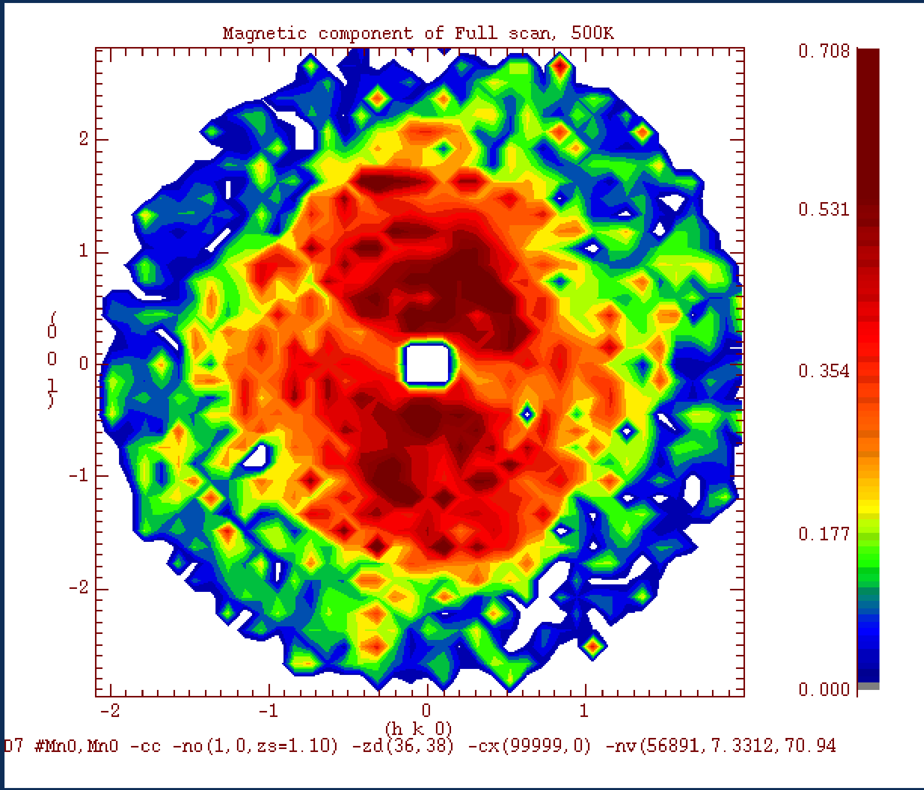


T J Sato et. al., PRB, 2000, vol. 61 (1), pp476-486

Persistent paramagnetic correlations in MnO



T = 150 K



T = 500 K

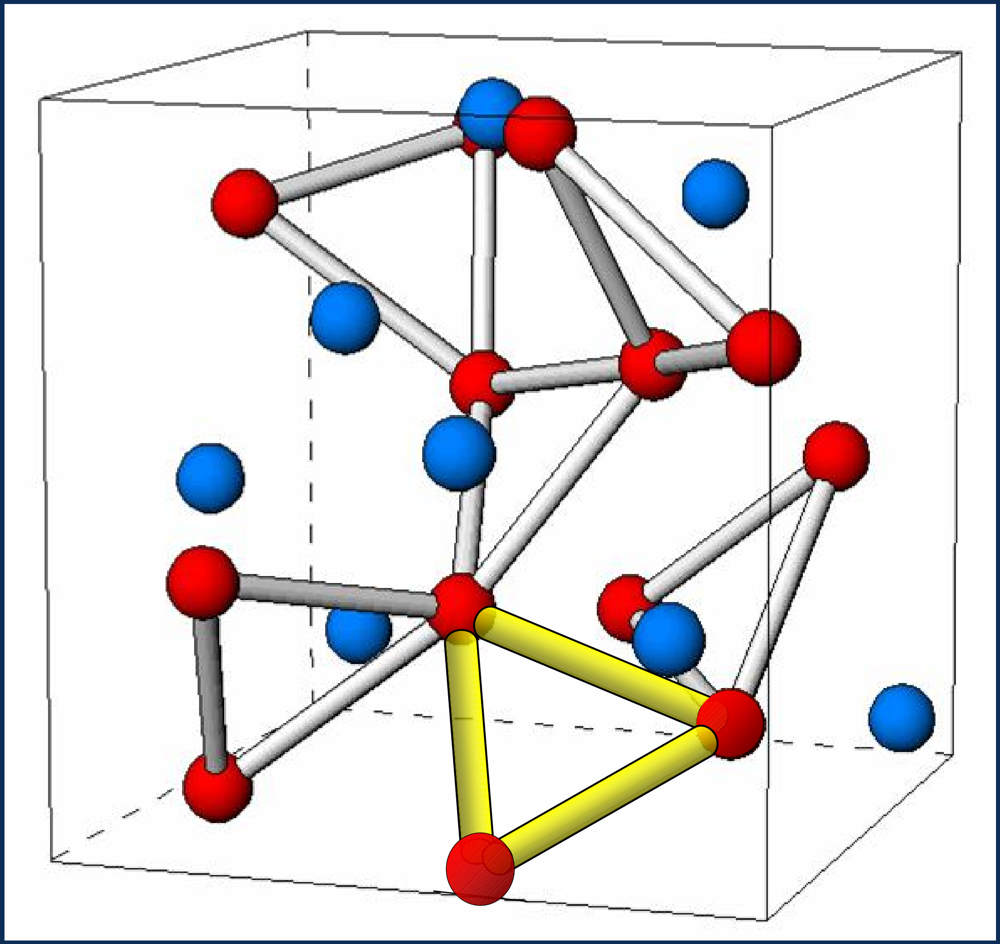
J R Stewart and D McK Paul, 2001 unpublished

β-Mn

- Simple cubic $P4_132$
- a = 6.32Å
- 8 site I (blue) atoms (non-magnetic)
  12 site II (red) atoms (magnetic)
- Apparent frustration between triangularly coordinated site II atoms in "distorted windmill" structure
- Perfect frustration for:

$$y = \frac{9 - \sqrt{33}}{16} = 0.20346..$$

- But degenerate only along <1 1 1>



Canals and Lacroix, Phys. Rev. B, **61**, 11251 (2000)

Disorder in frustrated β-Mn alloys

- Several studies carried out on D7, looking at nuclear and magnetic correlations in doped β-Mn alloys

β-Mn(Al)	- Al expands lattice, sits on site II
β-Mn(In)	- In expands lattice, sits on site II but less chemical disorder than Al
β-Mn(Co)	- Co donates electrons, sits on site I

- Restricted to use alloys since a spin-glass magnetic ground state is formed. Needed to ensure full integration over spin-fluctuations.

Polarization analysis studies of disordered magnets

Within the quasi-static approximation

$$\left(\frac{ds}{d\Omega}\right)_M = \left(\frac{g\,e^2}{2m_e}\right)^2 g_s^2 f(\boldsymbol{\kappa})^2 q^2 \sum_{i,j} e^{i\boldsymbol{\kappa}.(\mathbf{R}_i-\mathbf{R}_j)} < S_i^{\;a} >< S_j^{\;b} >$$

Taking the polycrystalline average:

$$\left(\frac{ds}{d\Omega}\right)_M = \frac{2}{3}\left(\frac{g\,e^2}{2m_e}\right)^2 g_s^2 f_B^2(\boldsymbol{\kappa}) S(S+1)\left[1+\sum_i \left\{c+(1-c)a(R_i)N_i \frac{\langle S_0.S(R_i)\rangle}{S(S+1)} \frac{\sin k R_i}{k R_i}\right\}\right]$$

with the polycrystalline average of the nuclear cross section

$$\left(\frac{d\sigma}{d\Omega}\right)_N = c(1-c)(b_A-b_B)^2\left[1+\sum_i \alpha(R_i)\frac{\sin \kappa R_i}{\kappa R_i}\right]$$

Disorder in β -Mn alloys

β -Mn is non-centrosymmetric so polycrystalline average of nuclear cross section for just site II is rather complex:

$$\left(\frac{ds}{d\Omega}\right)_N = c(1-c)(b_A - b_B)^2\left[1 + 6a_1\frac{\sin kR_1}{kR_1} + 2a_2\frac{\sin kR_2}{kR_2} + 2a_3\frac{\sin kR_3}{kR_3} + \dots\right.$$ to 4Å

$$+4a_4\frac{\sin kR_4}{kR_4} + 2a_5\frac{\sin kR_5}{kR_5} + 4a_6\frac{\sin kR_6}{kR_6} + 4a_7\frac{\sin kR_7}{kR_7} + \dots$$ to 5Å

$$+4a_8\frac{\sin kR_8}{kR_8} + 4a_9\frac{\sin kR_9}{kR_9} + 2a_{10}\frac{\sin kR_{10}}{kR_{10}} + 4a_{11}\frac{\sin kR_{11}}{kR_{11}} + \dots$$ to 6Å

…..etc

and similarly for the magnetic cross section

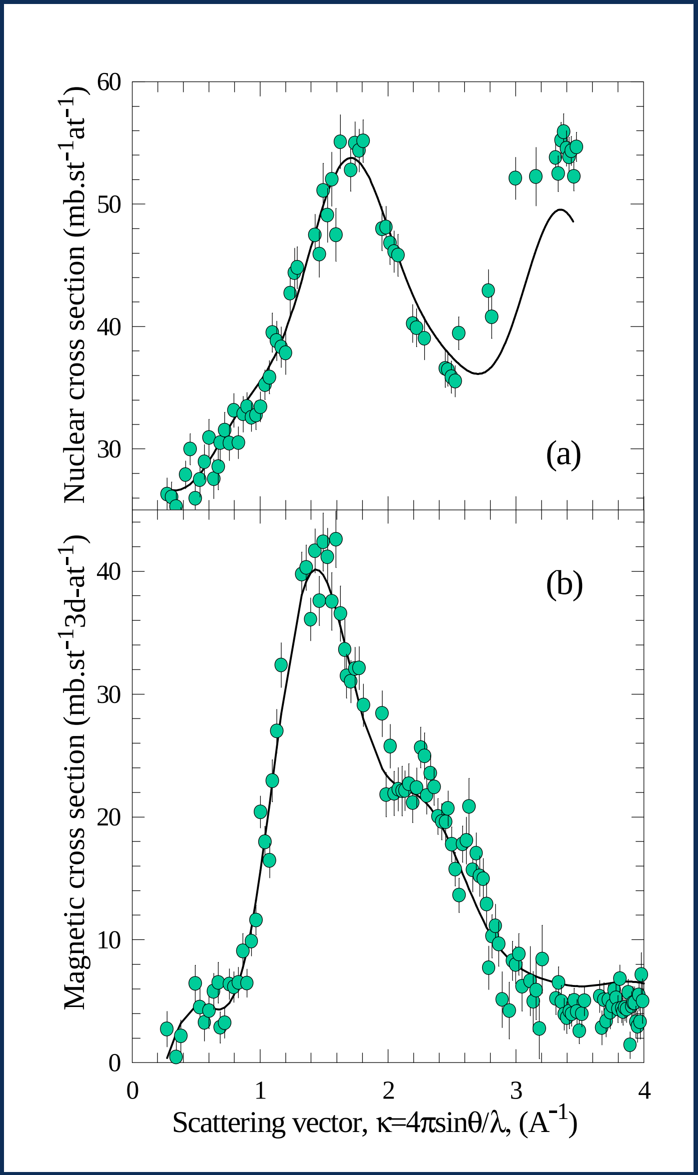
A direct least squares fit is not appropriate…..

…..instead use Monte Carlo procedures

Reverse Monte Carlo procedure

- Simulate a β -Mn lattice of $6 \times 6 \times 6$ unit cells

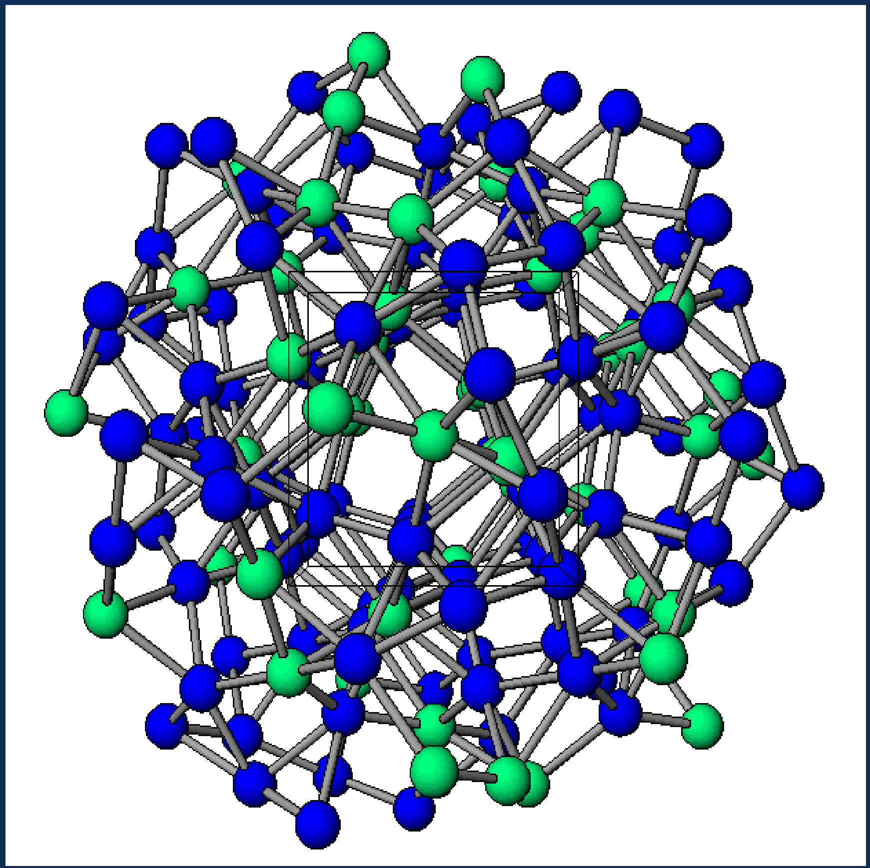
- Distribute Al atoms at random and exchange positions, calculating nuclear cross section and minimising χ^2



J. R. Stewart, et. al., J. Appl. Phys. 87, 5425 (2000)

Reverse Monte Carlo procedure

- Simulate a β -Mn lattice of $4\times4\times4$ unit cells with periodic boundary conditions
- Distribute Al atoms at random on site II and exchange positions, calculating nuclear cross section and minimising χ^2
- Use resulting lattice as input for magnetic simulation

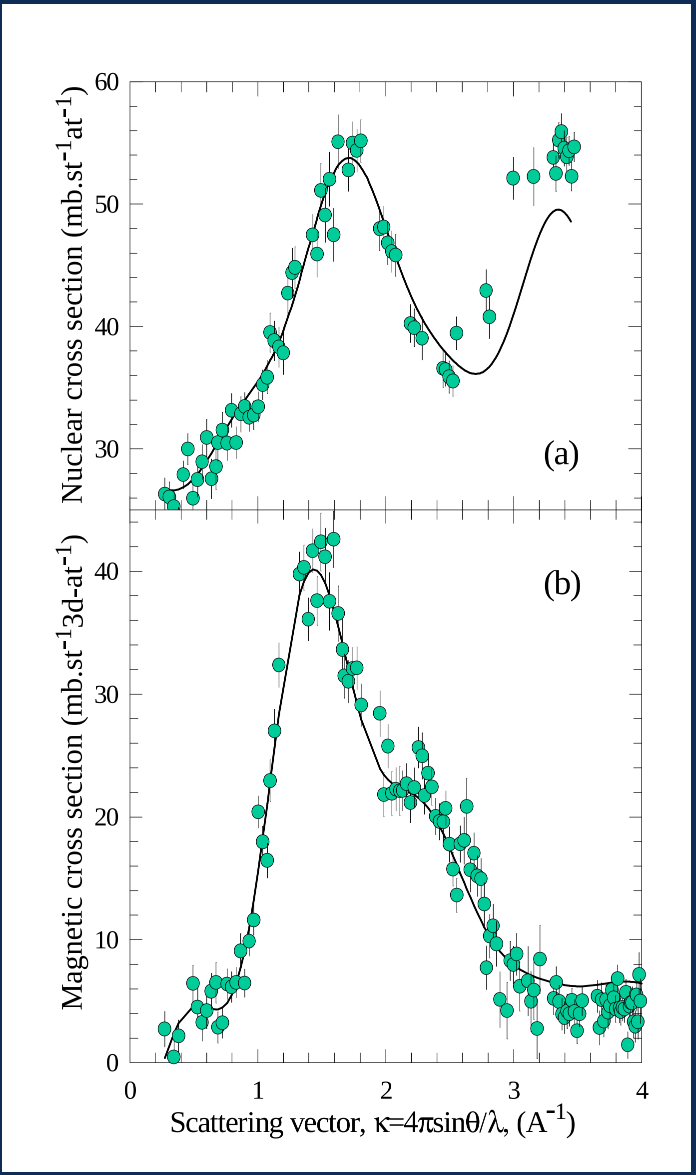


J. R. Stewart, et. al., J. Appl. Phys. 87, 5425 (2000)

Reverse Monte Carlo procedure

- Simulate a β -Mn lattice of 4×4×4 unit cells with periodic boundary conditions
- Distribute Al atoms at random on site II and exchange positions, calculating nuclear cross section and minimising χ^2
- Use resulting lattice as input for magnetic simulation
- Place random Heisenberg spins of unit length on Mn sites and reorient spin directions, adjusting S(S+1), calculating magnetic cross section and minimising χ^2

J. R. Stewart, et. al., J. Appl. Phys. 87, 5425 (2000)



β -MnAl alloys

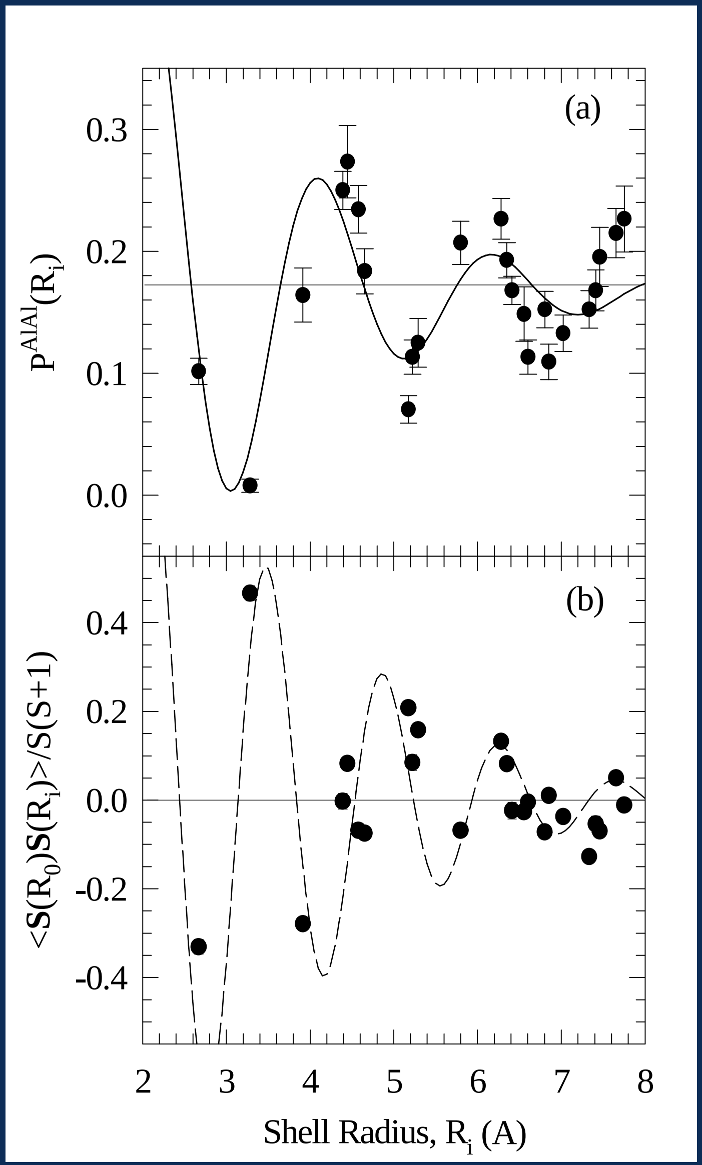
Structural correlations

$P^{AlAl}(R_i)$ is oscillatory with a period of 3Å, independent of concentration, and is exponentially damped with a range parameter that decreases with increasing concentration

Magnetic correlations

Spin correlations are predominantly antiferromagnetic and heavily damped.

	Q_{peak} (Å^{-1})	~ ξ (Å)
β -Mn(3at%Al)	1.53	5.6
β -Mn(6at%Al)	1.46	5.2
β -Mn(10at%Al)	1.41	5.0
β -Mn(20at%Al)	1.32	~4.5



J. R. Stewart, et. al., J. Appl. Phys. 87, 5425 (2000)

β -MnAl alloys

Structural correlations

$P^{AlAl}(R_i)$ is oscillatory with a period of 3Å, independent of concentration, and is exponentially damped with a range parameter that decreases with increasing concentration

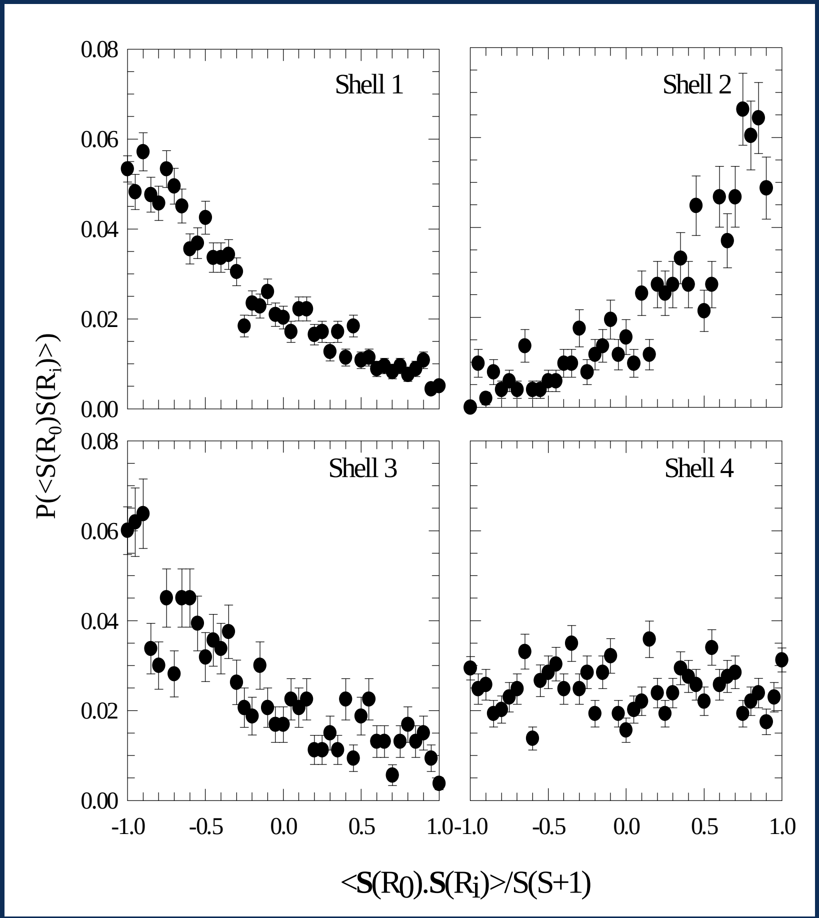
Magnetic correlations

Spin correlations are predominantly antiferromagnetic and heavily damped.

Within each shell the spin correlations

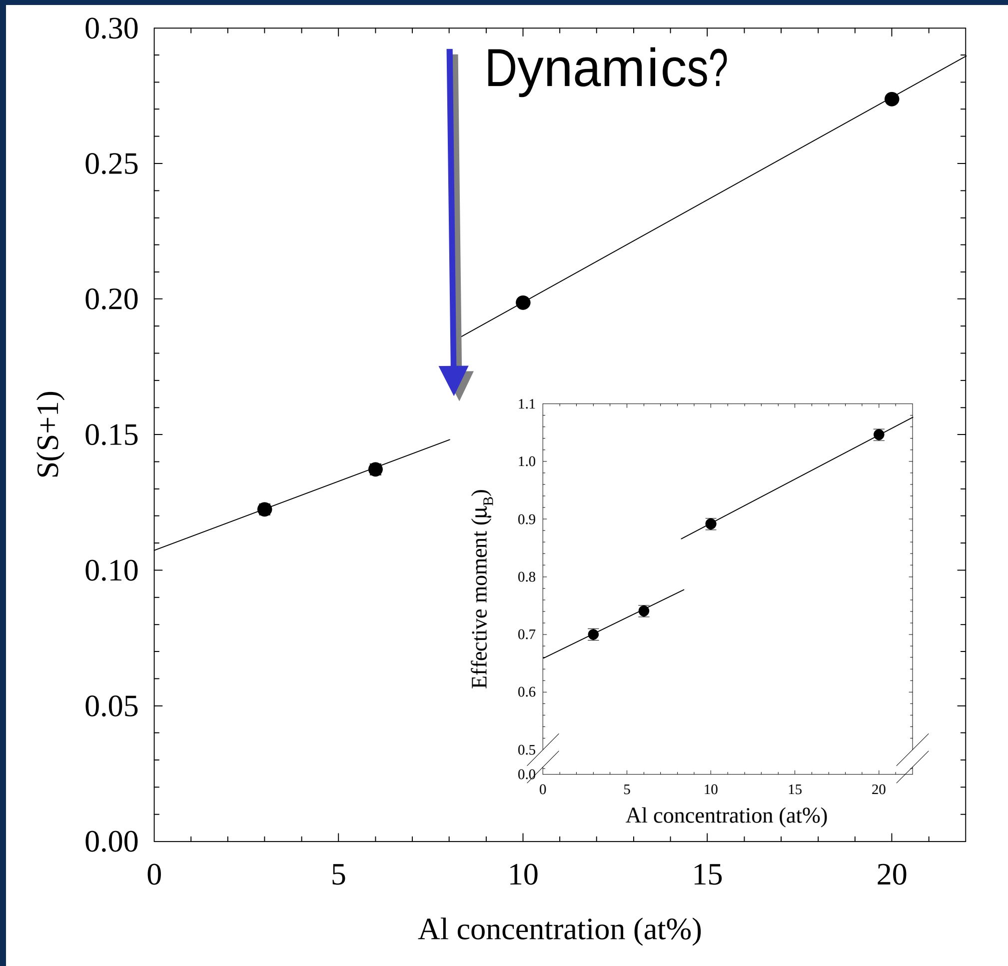
$$\frac{\langle S_0 S(R_i)\rangle}{S(S+1)}$$

are widely distributed



J. R. Stewart, et. al., J. Appl. Phys. 87, 5425 (2000)

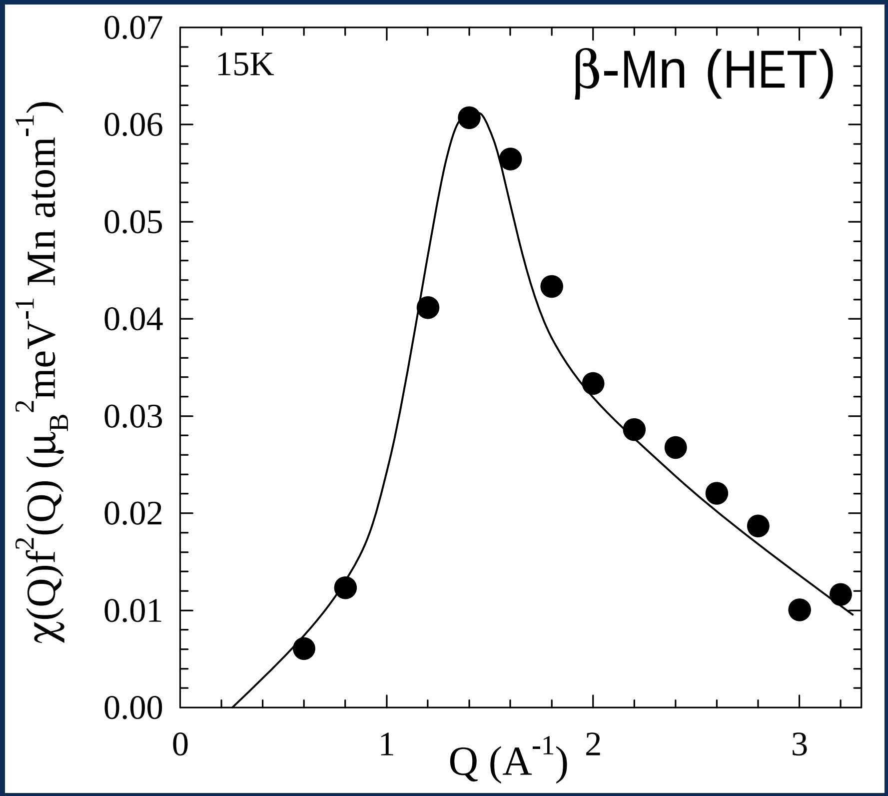
β -MnAl alloys



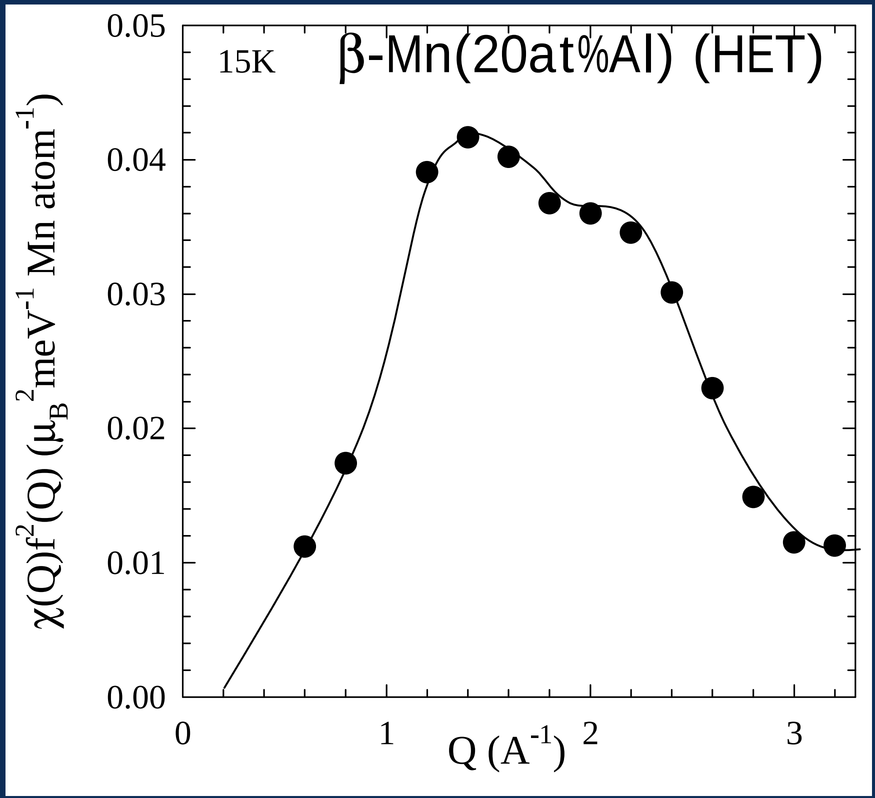
The Mn moment at high concentrations is in close agreement with NMR estimates (~1.1μ_B) BUT…………..

Compare with full integration....

- Actually, moments are roughly the same across the series
- Change of moment must be a dynamical phenomenon...



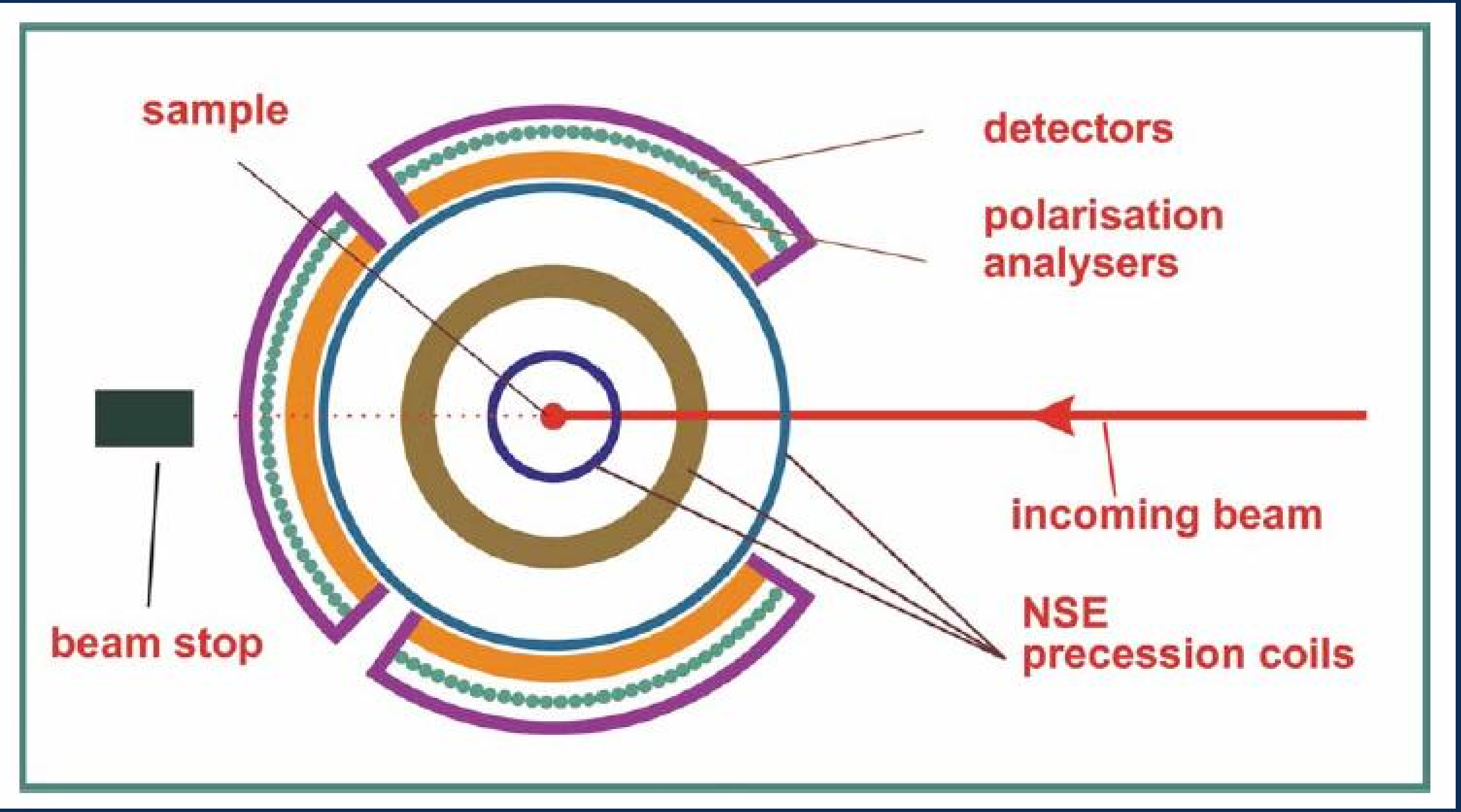
- μ = 1.36 μ_B/Mn atom



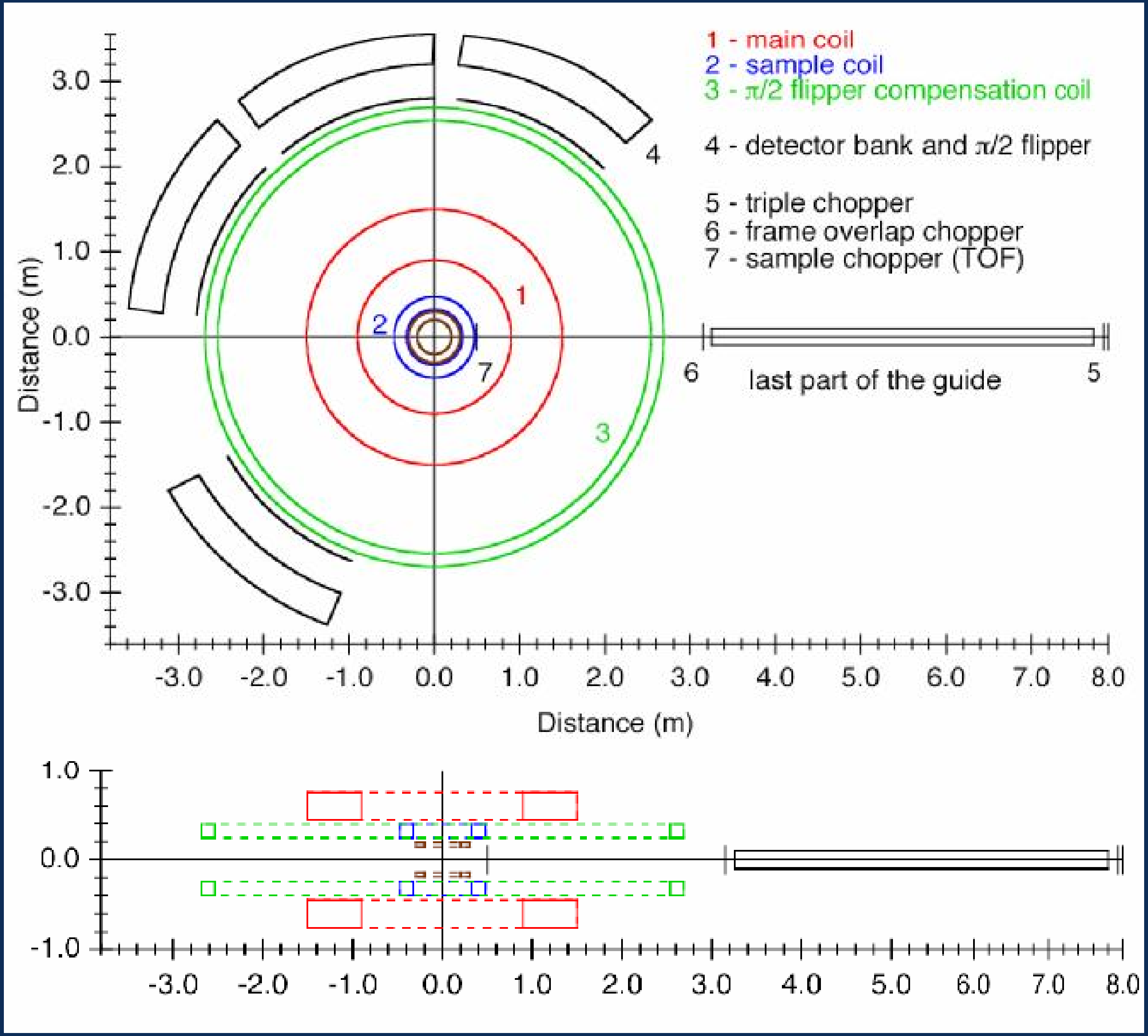
- μ = 1.44 μ_B/Mn atom

Pulsed Sources?

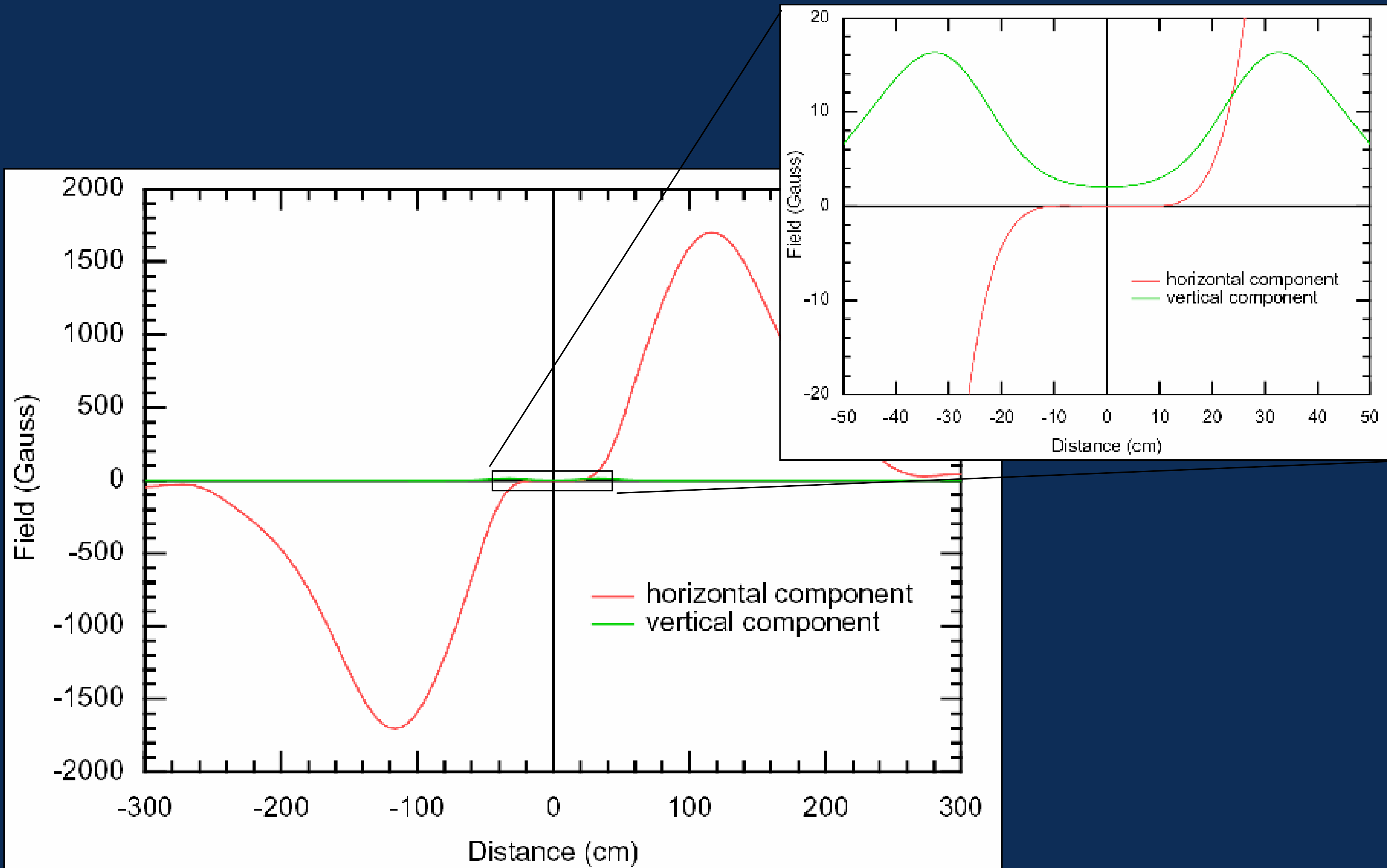
- Proposed D7/SPAN spectrometer for ESS
  (C Pappas, G Ehlers, J R Stewart and F Mezei)



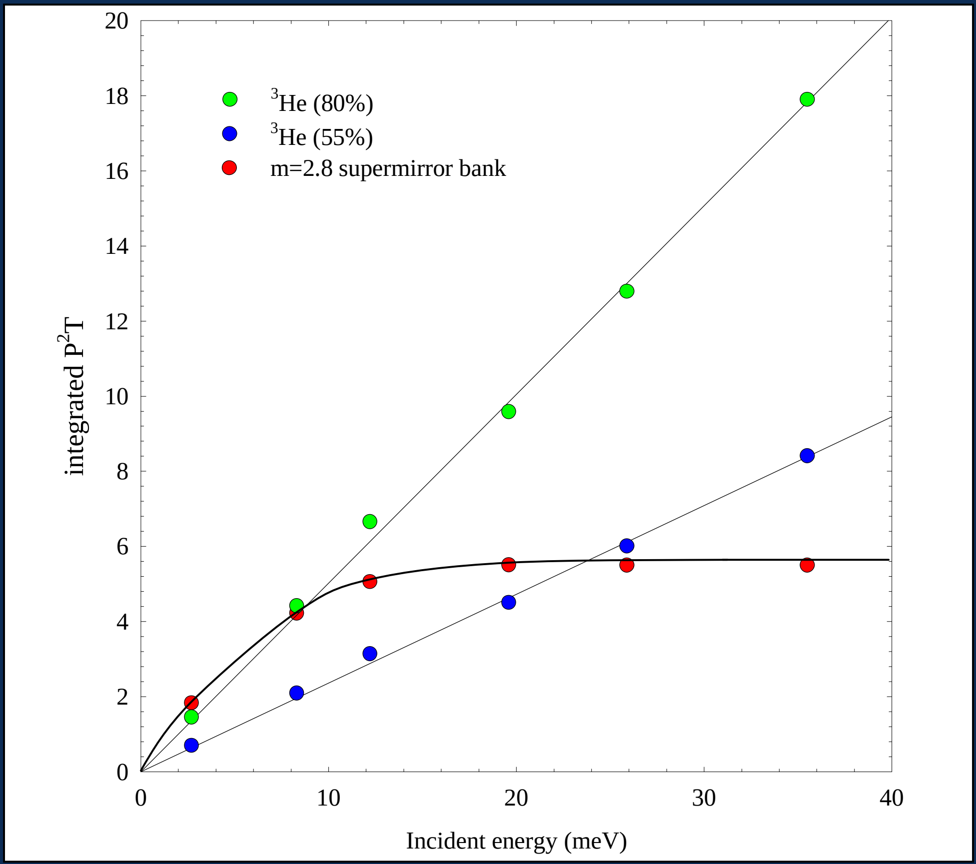
D7 / SPAN

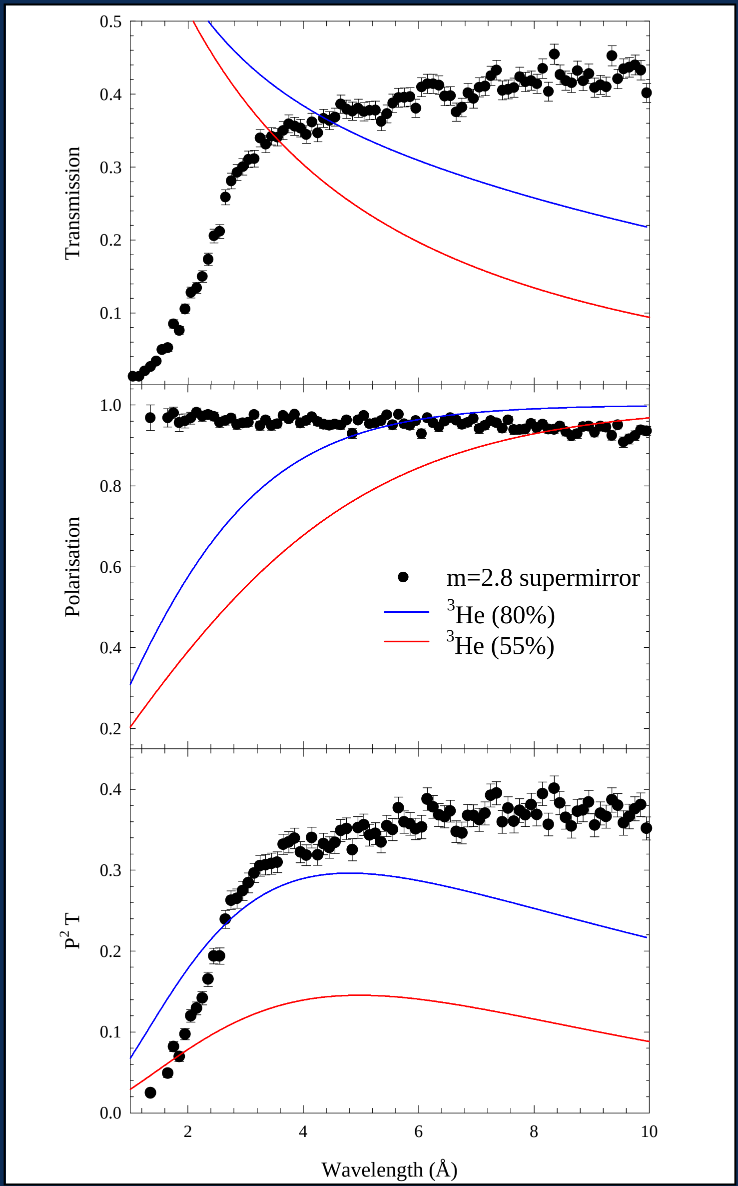

1 - main coil
2 - sample coil
3 - π/2 flipper compensation coil
4 - detector bank and π/2 flipper
5 - triple chopper
6 - frame overlap chopper
7 - sample chopper (TOF)
last part of the guide
Distance (m)
Distance (m)
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-3.0 -2.0 -1.0 0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0
1.0
0.0
-1.0
-3.0 -2.0 -1.0 0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0

D7/SPAN field geometry



Supermirrors vs. ^{3}He

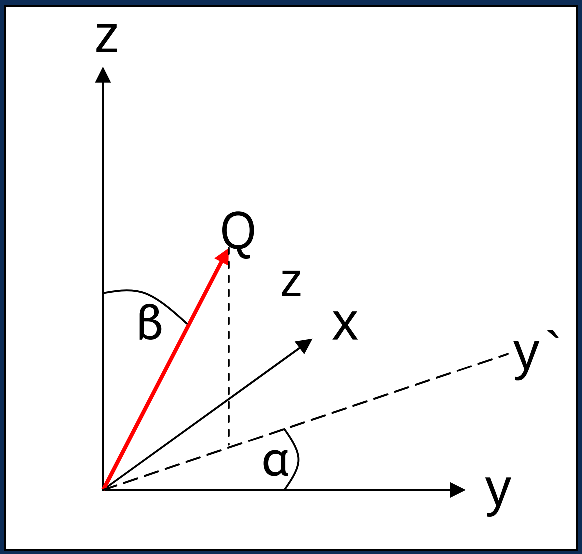




^{3}He wins for wavelengths < 3Å
Needs v. clean magnetic environment
(prob. Not compatible with NSE)

3 directional PA on a general multidetector

All PA diffuse scattering takes place using a “flat cone” geometry. But for a general PSD multidetector we have the geometry



So k is such that:

$$\frac{\boldsymbol{\kappa}}{k} = \begin{pmatrix} \sin a \sin b \\ \cos a \sin b \\ \cos b \end{pmatrix}$$

Stewart and Andersen, not yet published….

NEUTRONS FOR SCIENCE

3 directional PA on a general multidetector

We find the powder averaged cross-sections, where $M_x^2 = M_y^2 = M_z^2$

Where we include the nuclear and spin-incoherent contributions

$$\frac{\partial^2 s_{\uparrow\downarrow}^{z}}{\partial\Omega\partial E} = \frac{1}{2}M(1+\cos^2 b) + \frac{2}{3}SI$$

$$\frac{\partial^2 s_{\uparrow\downarrow}^{y}}{\partial\Omega\partial E} = \frac{1}{2}M(1+\cos^2 a\,\sin^2 b) + \frac{2}{3}SI$$

$$\frac{\partial^2 s_{\uparrow\downarrow}^{x}}{\partial\Omega\partial E} = \frac{1}{2}M(1+\sin^2 a\,\sin^2 b) + \frac{2}{3}SI$$

$$\frac{\partial^2 s_{\uparrow\uparrow}^{z}}{\partial\Omega\partial E} = \frac{1}{2}M\sin^2 b + \frac{1}{3}SI + N$$

$$\frac{\partial^2 s_{\uparrow\uparrow}^{y}}{\partial\Omega\partial E} = \frac{1}{2}M(1-\cos^2 a\,\sin^2 b) + \frac{1}{3}SI + N$$

$$\frac{\partial^2 s_{\uparrow\uparrow}^{x}}{\partial\Omega\partial E} = \frac{1}{2}M(1-\sin^2 a\,\sin^2 b) + \frac{1}{3}SI + N$$

NB:
Setting $\beta = 90°$
Brings us back to original equations

3 directional PA on a general multidetector

Separation

Not really:

$$\frac{\partial s^{x}_{\uparrow\downarrow}}{\partial\Omega\partial E} + \frac{\partial s^{y}_{\uparrow\downarrow}}{\partial\Omega\partial E} - 2\frac{\partial s^{z}_{\uparrow\downarrow}}{\partial\Omega\partial E} = \frac{M}{2}(3\cos^2 a - 1)$$

$$2\frac{\partial s^{z}_{\uparrow\uparrow}}{\partial\Omega\partial E} - \frac{\partial s^{y}_{\uparrow\uparrow}}{\partial\Omega\partial E} - \frac{\partial s^{x}_{\uparrow\uparrow}}{\partial\Omega\partial E} = \frac{M}{2}(3\sin^2 a - 2)$$

But this doesn't really matter since both α is known if k is known – and k is known exactly assuming energy analysis is involved – easy on a pulsed source

<u>Conclusions:</u>

No problem if time-of-flight is used
But must restrict geometry to α = 90° for diffraction measurements.

Conclusions

- Polarized neutrons: necessary for magnetic diffuse scattering studies
- Diffuse scattering/Spin-echo hybrids: Compatible wavelength bands and SNR requirements. (may also be compatible with polarimetry over wide angles)
- TOF diffuse spectrometer: Use of truly general multidetector big advantage for single crystal studies – and ideally suited to a pulsed source

Acknowledgements

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